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MINIMUM INPUT TECHNIQUES FOR RESTORING VALLEY OAKS ON HARDWOOD RANGELAND

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COSUMNES RIVER PRESERVE

Methods

The Cosumnes River Preserve is on level ground at an average elevation of 10 feet in the Sacramento Valley, 22 miles south of Sacramento. Average annual rainfall at the closest weather station (Lodi) is 16 inches. Rainfall at Lodi was 12.90 inches for the 1988-1989 season, 13.76 inches for the 1989-1990 season, and 7.55 inches for the 1990-1991 season.

We established experiments in four plots in three fields, all of which had been cleared of oaks and graded long before acquisition by The Nature Conservancy. Remnant valley oak riparian forest is found along the edges of the fields, and natural valley oak seedlings and saplings are found at the edge of field A and throughout field B. Due to its position along the undammed Cosumnes River, many parts of the preserve are intermittently flooded in the winter months. Field B was flooded for an extended period in early 1989 prior to seedling emergence, and also flooded in early 1990. All 3 fields were flooded for varying lengths of time in March 1991.

depth to hardpan

The soil in fields A and C is a poorly drained sandy clay loam underlain by calcareous clay and a hardpan. The depth to the hardpan is typically 20 to 40 inches, but is as little as 6 to 8 inches in some parts of field A, due to previous leveling of the field. Average depth to hardpan is greater on the south half of field A, where plot 1 is located, than on the north half, where plot 2 is located. A strip within plot 2 has evidently been tilled to break up the hardpan in the past. The exact nature and timing of the tillage operation is unknown, since it was done prior to acquisition of the land by The Nature Conservancy. The soil in field B is a silt loam underlain by silty clay loam and clay with an overall depth of 60 inches or more. Subsurface compaction was found in some portions of field B at depths of 10 to 18 inches.

Lepidium

tilling

Herbaceous vegetation varies substantially throughout the fields, but is generally dominated by a variety of introduced winter and summer annual grasses and forbs. In plot 2, there is an abrupt change in the herbaceous vegetation between the tilled strip and the remainder of the plot. The tilled strip is dominated by perennial pepperweed (*Lepidium latifolium* L.) and curly dock (*Rumex crispus* L.), whereas the remainder of the plot is dominated by winter annual grasses.

An ongoing program of valley oak restocking has been underway at the preserve since the fall of 1987 (Reiner and Griggs 1989), and our experimental sites were planted by Nature Conservancy volunteers according to the standard procedures at the preserve. Planting sites were prepared by scraping all vegetation off the soil surface in a 3 foot diameter circle. Two acorns were planted at each site within a 5 inch diameter plastic collar that extended approximately 4 inches below ground. A cylinder of aluminum window screen extending about 12 inches above ground level and folded closed at the top was attached to the top of the plastic collar (Bush and Thompson 1989), and served as the only protection against vertebrates. The screen cages were opened on top during the first season in all plots. Planting sites are arranged on a regular grid and spaced about 10 to 15 feet apart.

Since plantings were already in place at the start of our project, we limited our treatments to modifications of the Preserve's current post-planting inputs. Sites are routinely irrigated biweekly from the beginning of June through the end of August via drip irrigation with approximately 8 gal applied per irrigation. In addition, bare ground devoid of vegetation is maintained around each seedling by scalping the soil. Our experimental treatments included reducing or eliminating irrigation, and using a hay mulch around the planting site for weed control and moisture conservation. The experimental treatments used in each plot are summarized in Table 3-4.

All of the planting sites in field A were divided between plots 1 and 2. For plot 3, we established two permanent transects within field B, which has approximately 7000 planting sites. The transects were three rows wide and 70 or 71 rows long, parallel to each other, and separated by a distance of approximately 300 feet. A block of planting sites within a large planting at field C was used for plot 4.

Plots 1, 2 and 3 were planted in December 1988, and plot 4 was planted in November 1989. For plots 1 and 4, planting sites were excluded from all data analyses if seedlings were already dead or had not emerged by the beginning of the experiments. Some sites in plots 1 and 2 were lost in 1990 when a firebreak was plowed along one side of the planting. In the spring of 1991, planting sites in plot 4 were scalped, but mulch was not reapplied to all of the previously mulched sites. Sites where mulch was not reapplied were excluded from the 1991 data analyses. In plots 1 and 2, seedling heights were recorded every two weeks throughout the ~~irrigation season~~ in 1989 and 1990. End of season heights for all plots were collected in November 1989 and November 1990 through February 1991. Final seedling heights were ~~recorded in~~ June and July 1991.

Plots 1 & 2 at Visitor's Center - North

Results

Plot 1: Seedling emergence, survival, and condition

As of June 1989, seedlings had emerged at 87% of the planting sites in plot 1. Seedlings in only 4 sites (1.9%) died prior to July 1991 and survival did not differ between mulch or irrigation treatments. No irrigation was applied to plot 1 in 1991, and by July 1991, 16% of the seedlings had developed severe water stress symptoms (defined as chlorosis and/or necrosis affecting more than 50% of the leaves). Water stress symptoms were more common in mulched (24%) than in nonmulched seedlings (7%). Much of the mulch applied in June 1989 had broken down and disappeared by July 1991, although the amount of residual mulch varied between sites.

— i.e. 98% survival in July 91 of those that germ.

The seedlings were not protected from deer once they grew beyond the screen cages. The frequency of browsing damage during the summer of 1990 and at the February 1991 rating increased with increasing seedling height (Figure 3-9). Although mulched seedlings and those receiving biweekly irrigation had the highest incidence of browsing damage, when the effect of seedling height was partitioned out, browsing incidence was not influenced by irrigation or mulch. Damage due to insects was insignificant in this plot and in all of the other plots at Cosumnes during the course of our study. Mice were also very abundant in this plot, and tended to nest in the hay mulch, but caused no obvious damage to the oak seedlings.

Plot 1: Seedling growth

Seedling height growth over the course of the study is illustrated in Figure 3-10. By August of the first growing season (1989), seedlings in mulched sites were significantly taller than those in nonmulched sites, but the effect of irrigation frequency was not significant. Due to the amount of deer browsing that occurred in the plot in 1990, we analyzed the maximum seedling height recorded during the season rather than the final heights recorded in August 1990. In this analysis, effects of both irrigation frequency and mulch on total height were highly significant ($P<0.01$). Increases in seedling height due to mulch and biweekly irrigation were also significant at the February and July 1991 ratings. At each of these points, the average height increase due to mulch was greater than that due to increased irrigation frequency.

Virtually all of the separation between mulch and irrigation treatments appears to be due to differences that developed in the first growing season. We analyzed second season growth with analysis of covariance, using height in November 1989 as the covariate to correct for the influence of initial height on second-season growth. In this analysis, the differences between maximum height in 1990 and height in November 1989 did not vary significantly with treatment, although the effect of initial height was highly significant. Deer browsing was responsible for the reduction in average seedling height in all treatments seen between August 1990 and February 1991 (Figure 3-10).

Plot 2: Seedling emergence, survival, and condition

Seedlings had emerged at 91% of the planting sites in plot 2 as of June 1989. Among seedlings that had emerged by June 1989, seedling survival through 1991 was significantly lower in nonirrigated sites (54%) than in sites irrigated biweekly (98.5%). Virtually all of the observed seedling mortality occurred in the first year, and survival was essentially unchanged ~~from 1990 to 1991.~~ Many seedlings resprouted from the base following death of the shoot during the previous growing season. Among seedlings whose shoots had died by June 1989, 38% resprouted and were still alive in 1991.

till effect!

In the nonirrigated treatment, survival was markedly higher in the previously tilled strip (85%) than in the remainder of the plot (39%). Within this strip, there was no significant difference in survival between the nonirrigated and irrigated treatments.

No irrigation was applied to plot 2 in 1991. In July 1991, symptoms of water stress were equally common among seedlings that were previously irrigated (52%) or nonirrigated (54%). Browsing was much less common in this plot than in the adjacent plot 1, in large part due to the fact that average seedling heights were much shorter (Figure 3-11). Browsing damage rated in February 1991 was much more common in the irrigated (21%) than in the nonirrigated seedlings (1%), a pattern that reflects the difference in height between these treatments (Figures 3-9 and 3-11).

Plot 2: Seedling growth

For the analysis of seedling heights, seedlings within the previously tilled strip were considered to be in a separate block, and a two-way analysis of variance was performed with irrigation and block as main effects. Through July 1991, both block and irrigation treatment significantly affected seedling heights. Greater seedling growth was seen among irrigated seedlings and seedlings located within the previously tilled block (Figure 3-11). The magnitude of the overall block effect was virtually the same as that of irrigation at all rating dates. Irrigated seedlings in the nontilled block of plot 2 were considerably shorter than nonmulched seedlings irrigated every 2 weeks in plot 1, even though these two treatments were identical (compare Figures 3-10 and 3-11).

The height loss seen in the nonirrigated seedlings in the nontilled block (Figure 3-11) was due to shoot death and subsequent resprouting of seedlings from the base. In the irrigated treatment most seedlings were able to make continued growth from the previous year's stems.

TF-W

Plot 3: Seedling emergence, survival, and condition = 417 plant sites

By 15 July 1989, emergence was seen in 86% of the planting sites in this plot. Seedlings emerged at 11 additional sites between July and November 1989. In 1990, emergence was seen at 10 sites (2.4% of total) where no emergence had been observed in 1989, bringing the total emergence up to 91%. Emergence was equal in both transects.

Survival in plot 3 was high, and did not differ significantly between irrigation treatments or transects. As of July 1991, seedlings were present at 86% of the original planting sites. Among the sites where seedlings emerged in 1989, the overall rate of survival was 97% as of July 1991.

The incidence of deer browsing in the plot increased from 13% in November 1990, to 23% in July 1991. At both dates, browsing was significantly more common in the west transect, which is located within 200 feet of a densely wooded riparian corridor. In November 1990, browsing was more common among the taller basin and furrow irrigated sites than among the nonirrigated sites, but this difference was not seen in the July 1991 rating.

Plot 3: Seedling growth

Irrigation treatments significantly affected seedling height at each of the rating dates (Figure 3-12). By July 1991, there was no difference between the basin and furrow irrigation treatments, but previously irrigated seedlings averaged about 5 cm taller than the nonirrigated seedlings. Although irrigation was only applied in 1989, the height difference between irrigated and nonirrigated seedlings increased through 1990. A significant difference in seedling height between the two transects was detected at the November 1989 rating, but did not occur at later ratings.

Plot 4: Seedling emergence, survival, and condition

Emergence for the entire planting in field C was 73% (site basis) through the end of August 1990. Several factors may have contributed to the relatively poor emergence. Acorn quality was reportedly poor, and only a single acorn was used at some of the sites due to short supply. Furthermore, acorns were placed on the soil surface and covered with a thin layer of leaf litter, rather than being buried in the soil. Since rainfall was sparse through the winter following planting, some of the acorns might have dried out excessively.

Overall seedling survival into 1991 was 97%, and we did not observe any significant differences in survival due to mulch or irrigation treatments. Irrigation was continued into 1991 for only the biweekly irrigation treatment. The incidence of water stress symptoms in July 1991 was predictably higher among the nonirrigated sites (31%) and sites irrigated once in 1990 (27%) than among the irrigated sites (2%). Water stress symptoms were also more prevalent among nonmulched sites (21%) than among mulched sites (10%).

Mulch had no effect on the incidence of deer browsing, but irrigated sites were more than twice as likely to be browsed than the nonirrigated and once-irrigated sites. In July 1991, 29% of the seedlings irrigated biweekly were browsed, compared to 12% in the other two treatments. Mice were also abundant in this field, but no evidence of damage caused by mice was seen.

After irrigation commenced in 1990, a number of the irrigated seedlings in one portion of field C began to die rapidly. By 18 June 1990, many of the irrigated seedlings in this area had died, although rapid shoot death was not seen in the nonirrigated and once-irrigated treatments. Many of the affected seedlings were girdled by decay that originated at or near the point of acorn attachment. Recently killed seedlings did not have significant root decay.

The soilborne fungus *Macrophomina phaseolina* (Tassi) Goid. was recovered from symptomatic seedlings submitted to Tim Tidwell at the California Department of Food and Agriculture Analysis and Identification Laboratory. Soil samples were subsequently collected and submitted to Dr. Arthur McCain at U.C. Berkeley for an assay of *M. phaseolina* inoculum density. The assay showed the presence of *M. phaseolina* (6 to 11 sclerotia/g soil) in both affected and unaffected portions of the field. Soil chemical analyses were also performed on soil samples from affected and unaffected portions of the field. The only significant finding from these tests was a skewed calcium to magnesium ratio, which was more extreme in the affected part of the field (1:9) than in the unaffected portion (1:4.8). A low calcium to magnesium ratio can induce potassium deficiency in plants and promotes deflocculation of soil aggregates.

Plot 4: Seedling growth

In the first season of growth, only irrigation affected seedling heights. Seedlings irrigated biweekly were significantly taller than those that received a single irrigation or no irrigation. Seedling heights did not differ among the two latter treatments (Reynolds *in preparation*). Seedling heights measured in July 1991 showed a significant height increase in mulched over nonmulched seedlings, but the effect of irrigation was significant only at P=.07 (Figure 3-13).

Summary

The survival data from plots 3 and 4 clearly indicate that valley oak seedlings can be successfully established at this location without supplemental irrigation. However, results from plot 2 show that soil factors, such as the presence of a shallow hardpan, can limit seedling establishment. Despite the poor overall survival of nonirrigated seedlings in plot 2, good survival was seen in the previously tilled strip. This not only supports the hypothesis that soil depth was limiting survival in this plot, but illustrates a relatively simple corrective measure that can be used to improve site quality where compaction or depth to a hardpan is a problem.

As at Vacaville, weed competition had relatively little impact on seedling establishment. Seedling survival in plot 3 was quite good despite a lack of any weed control after planting. Oak seedlings were often difficult to locate in dense weed growth that was up to 4 feet high in plot 3 and in the tilled strip within plot 2, but oak seedlings still fared well in these areas. These observation suggest that valley oak seedlings are capable of competing successfully for soil moisture against some types of herbaceous vegetation, particularly if soil depth and moisture are adequate. Certain tall weeds may actually benefit oak seedling establishment, by providing shade and partial protection from herbivores such as deer.

A positive effect of mulch on growth was seen under both irrigated and nonirrigated regimes (Figures 3-10, 3-13). Furthermore, in plot 4, mulch appears to have delayed the onset of water stress symptoms. One anomalous effect of mulch was seen in plot 1, where mulched seedlings were more likely to develop water stress symptoms by July 1991, the first year that irrigation was not applied. We hypothesize that under frequent irrigation, the mulch may have promoted the development of a shallow root system, especially in sites with a shallow hardpan. Without supplemental irrigation, these seedlings may be more prone to water stress as the surface soil dries out.

Supplemental irrigation clearly increased seedling growth in all of the experiments at this location. However, growth effects equivalent to irrigation were obtained in plot 2 by planting in the tilled strip (compare the two middle lines of Figure 3-11), and in plot 4 by mulching (compare mulched, nonirrigated to nonmulched, irrigated in Figure 3-13). Therefore, while irrigation can clearly boost seedling growth at this location, similar benefits can be achieved through less intensive methods, such as preplant tillage and mulching.

One of the original ideas behind using irrigation in the restocking projects at the Cosumnes preserve was to promote rapid growth that would allow trees to escape deer browsing without protection. Trees were to be irrigated for the first two to three years only. However, in all of the plots at Cosumnes, irrigated seedlings, being taller, were more apt to be browsed than the shorter nonirrigated seedlings. Without protection from deer, early height gains due to irrigation may be offset by increased browsing, and the heights of irrigated and nonirrigated seedlings could converge within a few years.

If frequent irrigation is used to establish seedlings on marginal sites, such as in plot 2, problems may develop when irrigation is eventually terminated. In plot 2, previously irrigated seedlings showed as much water stress in July 1991 as the nonirrigated seedlings. In a 4 year old planting near field A, severe water stress symptoms began to develop in many trees early in the summer of 1991, the first season that biweekly irrigation was discontinued. Irrigation was subsequently applied and many trees showed signs of recovery. It remains to be seen how seedlings established under frequent irrigation will perform once irrigation is terminated, relative to seedlings established without supplemental irrigation.

DISCUSSION

Every input used in a restocking project has costs in terms of materials, labor, and/or unintended negative effects. In order to be cost-effective, each input should produce enough of a benefit to justify its costs. In the following discussion, we summarize the results of our demonstration projects and compare the relative costs and benefits of the cultural inputs we used to aid seedling establishment. General recommendations based on our results and ideas for future research are also presented.

Planting methods

We were able to successfully establish moderate to high percentages of valley oak seedlings without irrigation at several locations in the third year of drought conditions. Together with the results of studies discussed in Section 2, the demonstration projects clearly show that direct-seeded acorns can be used to restock valley oaks on hardwood rangeland. Considering the many advantages that acorns offer over transplants (Section 2), and the fact that they are essentially free, acorns are the best propagules to use in most restocking projects.

When relatively intensive site preparation is used, such as installing Vaca cages, it is most efficient to minimize the number of unsuccessful sites. We found that using several acorns per planting site was a simple and highly effective technique for minimizing the number of initially unsuccessful sites. This practice allowed us to attain high rates of emergence and survival on a planting site basis despite variable levels of acorn viability and seedling mortality. Similar results have been reported by Tietje et al (1991).

Our analyses indicate that there is no significant competition between valley oak seedlings within a single planting site, at least for the first year and a half. Tietje et al (1991) also found no adverse effects of having several closely-spaced seedlings per planting site. These results suggest that there is no advantage to thinning seedlings in at least the first one or two seasons. Furthermore, our ability to predict which seedling at a site will be the best adapted over the long term is limited, and future seedling mortality is likely to occur. Therefore, our current recommendation is to allow the seedlings at each planting site to self-thin, at least until they attain a size where competition between seedlings is likely.

At both Pepperwood and Cosumnes, emergence data indicate that in some cases, shoot emergence by valley oaks may be delayed by more than a year. Such delayed shoot emergence has been reported for two other California white oaks, Engelmann oak (*Q. engelmannii*) (Lathrop and Osborne 1990) and blue oak (Tecklin and McCreary 1991). This phenomenon may represent another adaptation of *Q. lobata* to adverse growing conditions. The possibility of delayed emergence should be considered before plans are made to replant sites that show no emergence in the first year after planting.

Herbivory

Cattle and deer

Although caging individual planting sites is relatively expensive in terms of materials and labor (Table 3-1), protection from browsing is necessary in areas grazed by either cattle or deer. Our data clearly show that both cattle and deer can severely limit seedling growth, and that Vaca cages and deer cages effectively protected seedlings from browsing. Where existing seedlings or saplings can be located, as at Wantrup, caging individual plants to protect against deer and cattle may be the only input required for restocking. Overall costs can be reduced if cages are removed and reused after trees have grown above the browse line.

In our experience, protecting seedlings with either Vaca or deer cages has not been associated with any obvious negative effects. However, Vaca cages may require maintenance, since they can be damaged by cattle (Appendix 1). It may be possible to reduce or eliminate maintenance requirements by using higher grade materials. We observed that damage to Vaca cages tended to increase with increasing intensity and duration of grazing. Thus, grazing patterns need be considered when weighing the costs and benefits of different cage designs and materials. Construction of Vaca cages is described in detail in Appendix 1.

Small herbivores

Damage from insects was insignificant at all of the demonstration projects, despite a complete lack of protection at three of the four locations. At Cosumnes, protection was provided for only a few months during the first growing season. Although damage by leaf-chewing insects could be important in some locations and years, our results suggest that routine protection against insect herbivory is not likely to be cost effective in most plantings.

The significance of damage and seedling losses caused by rodents is much less clear. Gophers were present at all planting sites, but damage from gophers was insignificant. Ground squirrels were present only at the Wantrup demonstration project. Ground squirrels did excavate around planting sites located in close proximity to an active colony in a grazed field, but did not disturb planting sites located some distance away or in adjacent nongrazed fields. Even among sites excavated by ground squirrels, 58% contained live seedlings in 1991.

Aside from sites disturbed by ground squirrels, there was little evidence that planted acorns were dug up by other rodents. This suggests that using a planting depth of 2 inches was adequate to hold acorn losses to a minimum. Similar results are reported by Tietje et al (1991). At Pepperwood, emergence in some treatments was lower in the nongrazed field than in the grazed field, possibly due to activities of mice or voles. The highest levels of rodent damage were seen at Wantrup and Pepperwood, but levels of rodent damage varied between different fields. However, after one year, neither survival nor growth differed significantly between fields with the greatest and the least amounts of rodent damage.

Protecting planting sites from all types of rodents is particularly labor intensive. Wire mesh screening must be installed above and below ground to provide substantial protection against ground squirrels and gophers, and screening or very fine mesh must be used to exclude mice. Furthermore, the above-ground cages must be opened at some point to allow for seedling growth, which then exposes the seedling to herbivory.

Since seedlings were protected from small rodents only at Cosumnes, we do not know exactly how much benefit could have been gained by protecting seedlings at the other three locations. To date, damage and losses that could be attributed to rodents have been variable, but relatively low overall at all locations. It does not appear that the possible benefits of using complete rodent protection would have offset the costs of this input at our project sites.

As noted in Section 2, other options for reducing herbivory include avoidance and habitat modification. Avoidance is probably the most cost-effective strategy for minimizing herbivory caused by rodents. For example, the greatest levels of ground squirrel damage at Wantrup were seen near an obviously active colony in field 1. Acceptably low levels of rodent damage were achieved in this field by simply avoiding the most heavily colonized area. Relatively simple types of habitat modification may also be practical in some areas. The differences in small rodent damage between grazed and nongrazed fields at Wantrup and Pepperwood provide examples of the effect of habitat modification. However, environments unfavorable for one rodent species may be appealing to other species. For example, although mice and voles avoid areas without grassy cover, ground squirrels prefer such areas. In areas where avoidance and habitat modification are not viable options and rodent populations are high, it may be advisable to conduct a small test planting to assay the potential for rodent damage before resorting to more expensive protection or control measures.

Soil moisture

Soil characteristics

Results from the Cosumnes plots illustrate how soil characteristics interact with moisture stress. Survival of nonirrigated seedlings was low (39%) in the nontilled portion of plot 2, where rooting depth was severely limited, but high (97%) in plot 3, where soil conditions were favorable. In the untilled block of plot 2, even irrigation did not increase seedling heights to levels seen elsewhere at Cosumnes. Modification of the soil profile by tillage is probably the most cost-effective means for improving seedling establishment on such sites.

Unfortunately, various types of tillage operations, such as ripping or augering, can be relatively expensive and time consuming, especially in areas with uneven topography. It is therefore advisable to avoid these operations unless they are actually necessary. For example, at Vacaville, augering and soil probing provided no obvious benefit to seedling establishment, presumably because soil depth was not a limiting factor over most of the project area. Since soil characteristics can have a significant impact on restocking success, we believe that an adequate assessment of the soil at the planting site is a necessary and cost effective input.

Soil moisture conservation

Weed competition did not obviously limit seedling establishment at any of the project locations. Nonirrigated seedlings in plot 3 at Cosumnes had high rates of survival and adequate growth despite high weed populations. The use of herbicide to control weeds at Wantrup did not increase seedling emergence, survival, or growth. Since weed competition interacts with soil, environmental, and microclimate factors to affect soil moisture status, weed control alone may not always have a large impact on soil moisture. Also, different weed species vary in the degree to which they compete with oak seedlings for soil moisture (Gordon et al 1989). Weed control may not be critical where soil moisture is adequate and relatively noncompetitive weeds are present.

In all locations, mulched seedlings were significantly taller than nonmulched seedlings at some point within the first 18 months after planting. Mulch reduces both weed competition and evaporative moisture loss. Therefore, mulching may conserve soil moisture to a greater degree than can be achieved by weed control alone. In addition, organic mulches slowly release plant nutrients as they decompose, which may further promote seedling growth.

The effect of mulch on seedling emergence was quite variable. Mulch did not significantly affect emergence at Vacaville, but hay mulch was associated with decreased emergence at Wantrup. At Pepperwood, the generally positive effects of mulch on emergence differed between fields. These results indicate that mulch has the potential to adversely affect emergence under some conditions, and that care should be exercised when applying mulch at planting.

The cost of mulch compared to other cultural inputs is relatively low. Organic mulch can often be obtained free or at a nominal cost. Synthetic mulches are more expensive (Table 3-1), but may be longer lasting, depending on their resistance to ultraviolet light. Applying mulch can also be relatively labor intensive, depending on the type of mulch used and the accessibility of the site. Reasonable care must be used in selecting and applying mulch to avoid negative effects on seedling emergence. Overall, we believe that mulch is one of the most cost-effective methods for conserving soil moisture available, and is likely to be beneficial in most restocking projects.

Soil moisture augmentation

Irrigation increased seedling growth at all the demonstration projects where it was used, although the increases were not always statistically significant. However, first season survival was enhanced by irrigation in only one location, the nontilled block of plot 2 at Cosumnes, despite prevailing drought conditions at all locations.

Negative effects of irrigation were also seen in some locations. Irrigation was associated with increased small animal herbivory at Wantrup and postemergence damping-off in field C at Cosumnes. Furthermore, it is unclear at this point how frequently-irrigated seedlings at Cosumnes will fare once irrigation is discontinued. Continued monitoring of long-term growth and survival is necessary to determine the relative effectiveness of moisture conservation versus augmentation.

Given the high cost of irrigation, the difficulty of irrigating in many rangeland settings, and the modest benefits of irrigation, we do not believe that irrigation will be cost effective for most low-input restocking projects. In sites that are favorable for valley oaks, irrigation is not necessary to establish seedlings from acorns. In unfavorable and marginal locations, irrigation may provide short-term growth and survival increases. However, in the absence of other measures to improve site quality, we wonder if irrigation alone will ensure long-term survival of valley oak seedlings.

Suggestions for future research

It appears that valley oaks can be restocked using low input techniques tailored to overcome site limitations. However, the effects of the different treatments presented here are known only for the first one to three seasons after planting. Continued monitoring of the plantings will be necessary to determine if treatment effects persist or become damped out as seedlings become more established. Results from previous projects (Section 2) indicate that long-term survival may bear little relation to first year survival. With longer-term survival data, the cost-effectiveness of the different inputs could be calculated on the basis of the cost in materials and labor per each successful seedling. An example of such a calculation is presented in Appendix 2.

We generally concluded that small rodents such as mice and voles were not a major factor limiting seedling establishment and growth in the demonstration plantings. However, this conclusion is tentative because none of the projects included comparisons with planting sites that were protected from small rodents. Careful experiments are needed to show what impact these small rodents have on seedling emergence, survival, and growth. To be meaningful, these experiments should be conducted at plant densities typical of restocking projects, rather than in dense experimental plots. If significant impacts are identified, information will be needed on the relative importance of different rodent species, and monitoring guidelines should be developed that would allow one to characterize the risk of rodent damage at a given site.

Further investigation into the effects of herbaceous vegetation on valley oak seedling establishment may also be warranted. It would be useful to rank herbaceous species in terms of how severely they compete with valley oak seedlings. Such a ranking might identify potential nurse plants, i.e., noncompetitive species that might actually favor valley oak seedling establishment by providing shade and protection from browsing.

Observations and indirect evidence from various studies cited in Section 2 suggest that shade may be beneficial for establishing valley oak seedlings. Experiments comparing different levels of shading could be included within restocking projects to indicate whether shade, provided by other plants or synthetic materials, increases seedling growth and survival.

CONCLUSIONS

Choosing methods for planting valley oaks in rangeland situations involves a trade off between the costs of cultural inputs and desired survival and growth rates. At least over the short term, various cultural inputs may increase seedling growth and survival, but the additional cost and effort required for some inputs is substantial. Restocking can be achieved at minimum cost by selecting the inputs that are most critical for obtaining successful seedling establishment at a given site.

Selection of appropriate cultural inputs is complicated by several factors. There is not enough data to determine whether the effects of certain inputs, such as irrigation and mulching, will persist over the long term. If seedlings grown without these inputs show similar growth and survival after a period of years, it may be difficult to justify the additional expense that these inputs require. Furthermore, in some cases, cultural inputs may overcome one set of limitations only to have growth and survival limited by other factors. For example, at Cosumnes, irrigation accelerated plant growth by alleviating soil moisture limitations, but as a result, browsing by deer may now be the most important factor limiting plant growth.

Finally, some cultural inputs may have negative consequences as well as positive effects. If cattle grazing is terminated, the need to provide costly protection against cattle is eliminated, but weed competition and herbivory due to certain small rodents may be increased. Since the balance between positive and negative effects may vary from site to site, there is no single prescription for valley oak restocking that will be optimal for all locations. The guidelines presented in Section 4 are intended to assist in the analysis of a potential restocking site so that a site-specific restocking prescription can be developed.

Table 3-4. Summary of experimental designs for demonstration plots at the Cosumnes River Preserve.

Plot	1	2	3	4[1]
Field[2]	A	A	B	C
Date planted	11/88	11/88	11/88	11/89
Date treatments started	6/89	6/89	6/89	5/90
Number of planting sites monitored	216	168 all 384 trees.	423	178
Irrigation treatments (Type/Interval/Years)	Drip/2 wk/89,90 Drip/4 wk/89,90 ---	Drip/2 wk/89,90 None ---	Basin/4 wk/89 Furrow/4 wk/89 None	Drip/2 wk/90,91 Drip/1 time/90 None
Mulch treatments	With, without	---	---	With, without
Weed removal	At planting	At planting	At planting, basin only	At planting, spring 91

[1]The experiment in this plot also served as the basis for a MS thesis (Reynolds *in preparation*).
[2]Locations of fields within the preserve:
- A - Along Franklin Blvd., north of trailer pad = VC-N (Trailer Pad-N)
- B - West of "tall forest" area and north of the Cosumnes River = W Bottoms
- C - Southwest of equipment yard — = Two Oaks

285
186
196
467

YOU ARE
NOT MISSING
pages 48-55

They were not
included in ORIGINAL

Figure 3-9. Relationship between seedling heights and deer browsing incidence in field A (combined data for plots 1 and 2) at the Cosumnes River Preserve in February 1991.

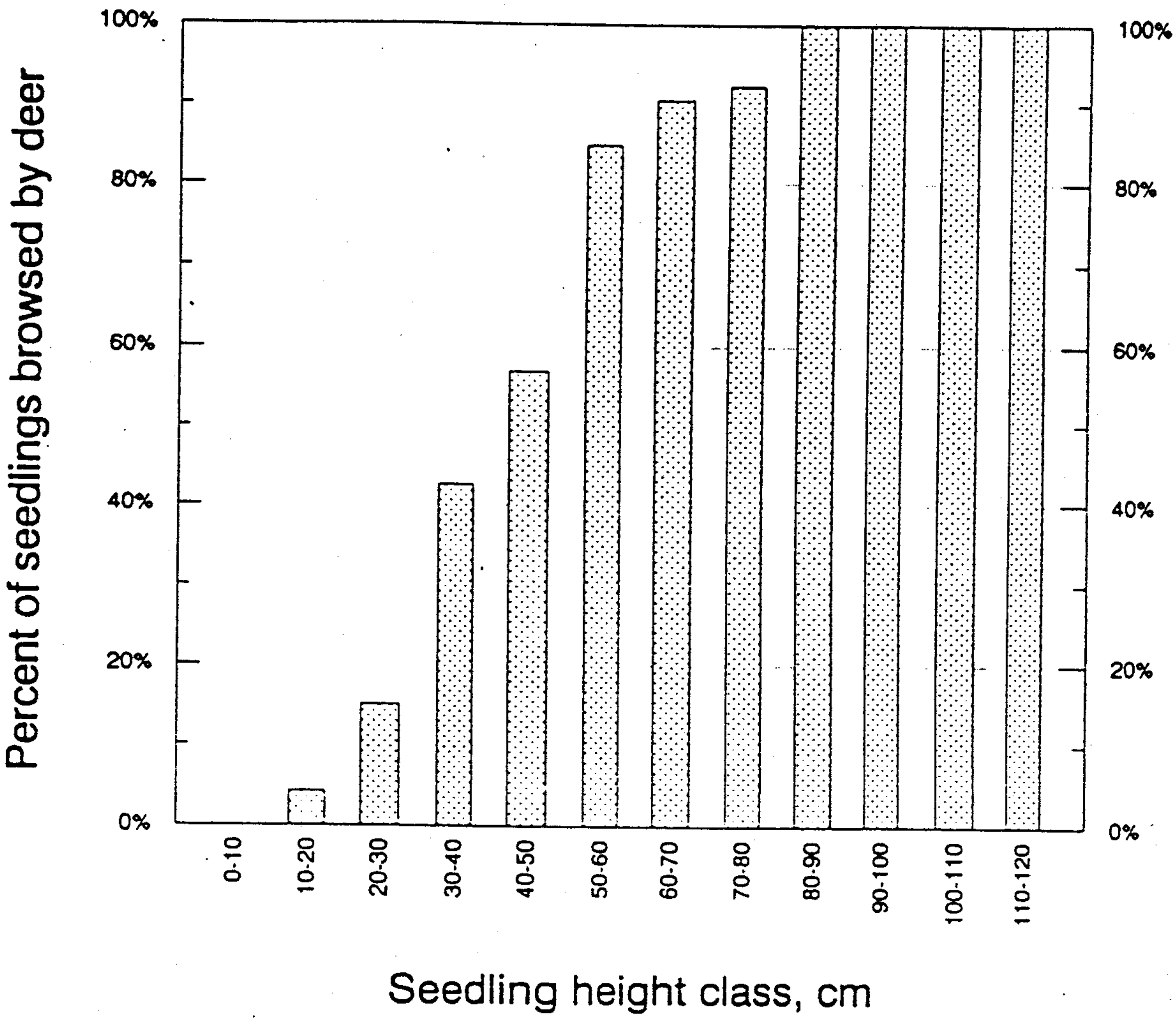


Figure 3-10. Average seedling heights by mulch and irrigation frequency in plot 1 at the Cosumnes River Preserve. Seedlings grew from acorns planted December 1988. Seedlings were not irrigated in 1991.

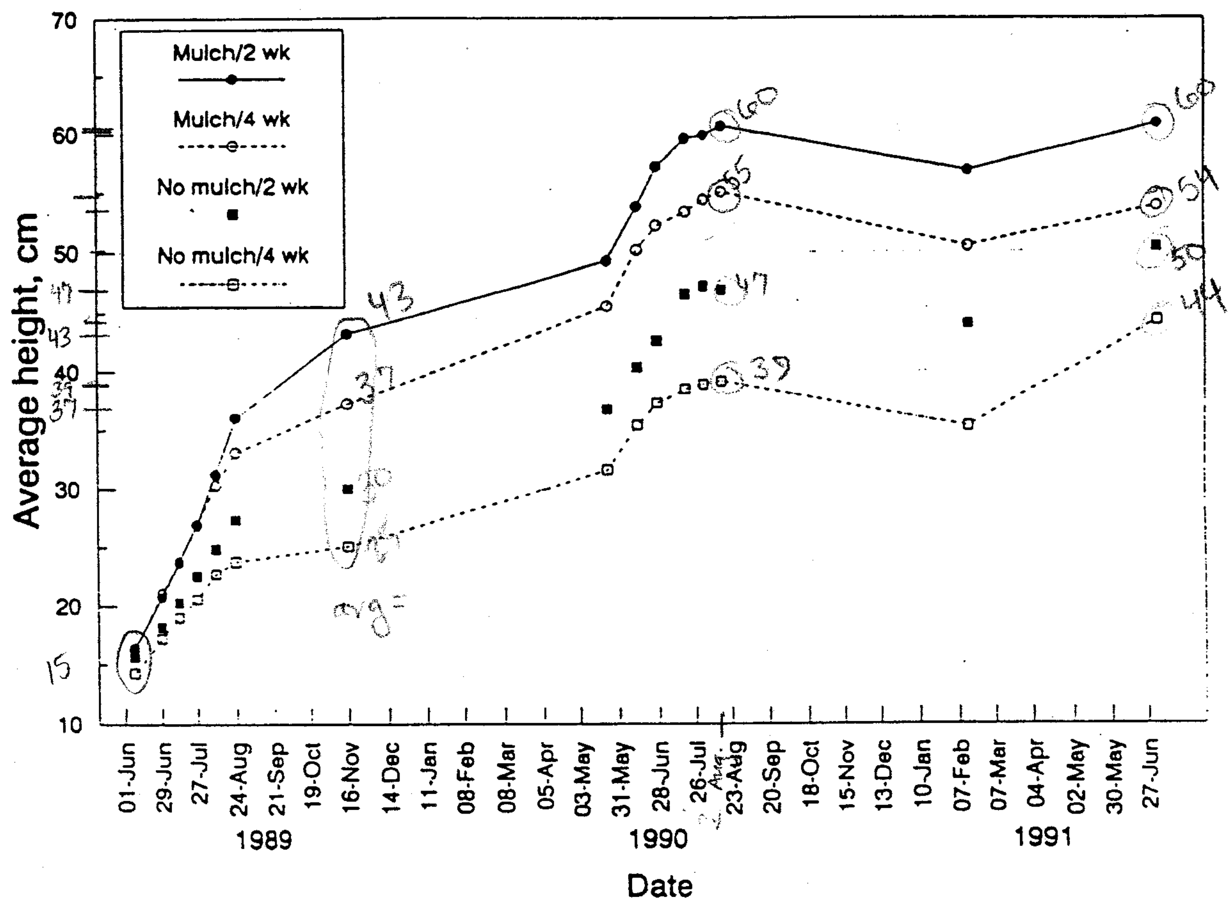
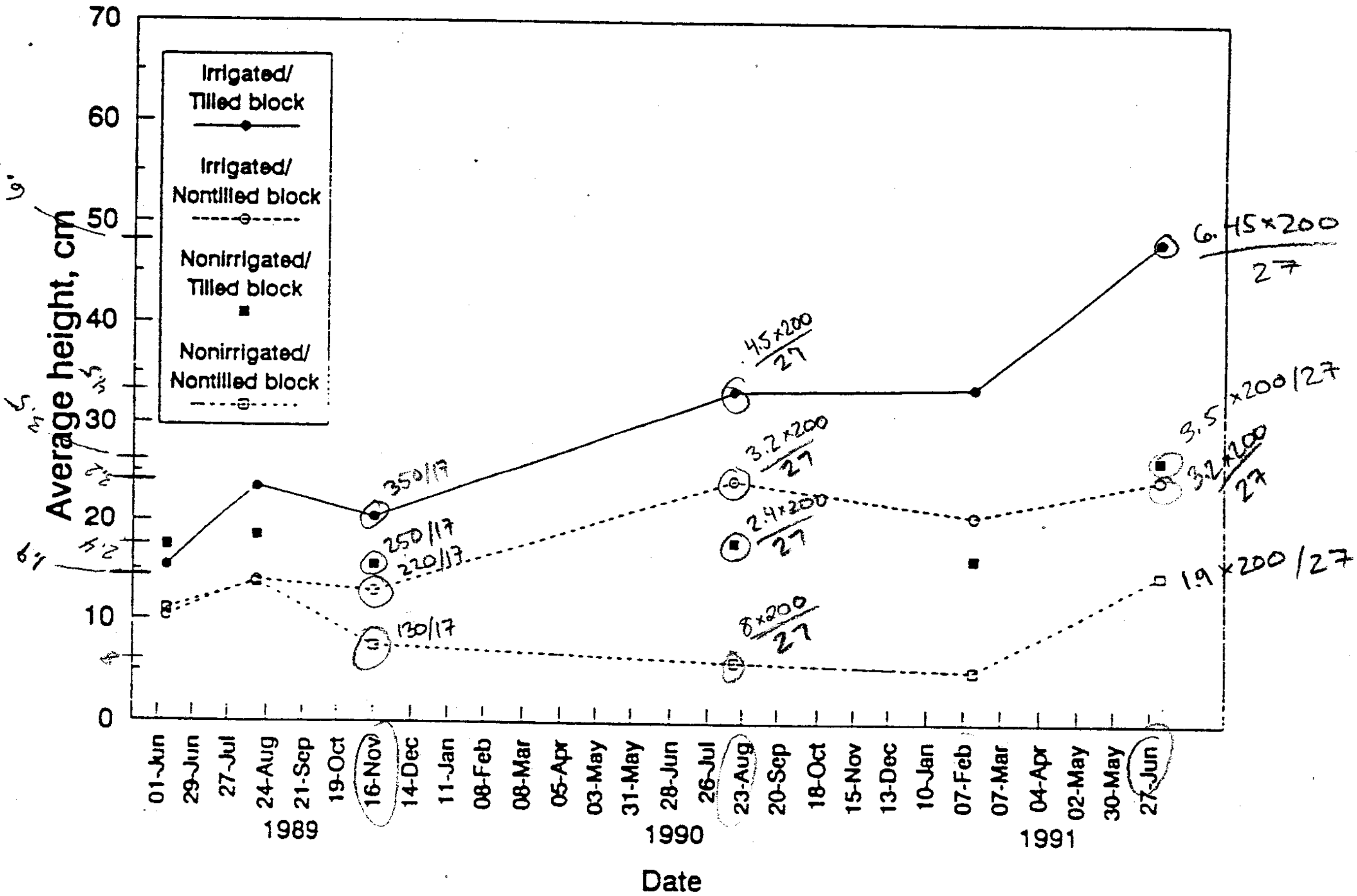
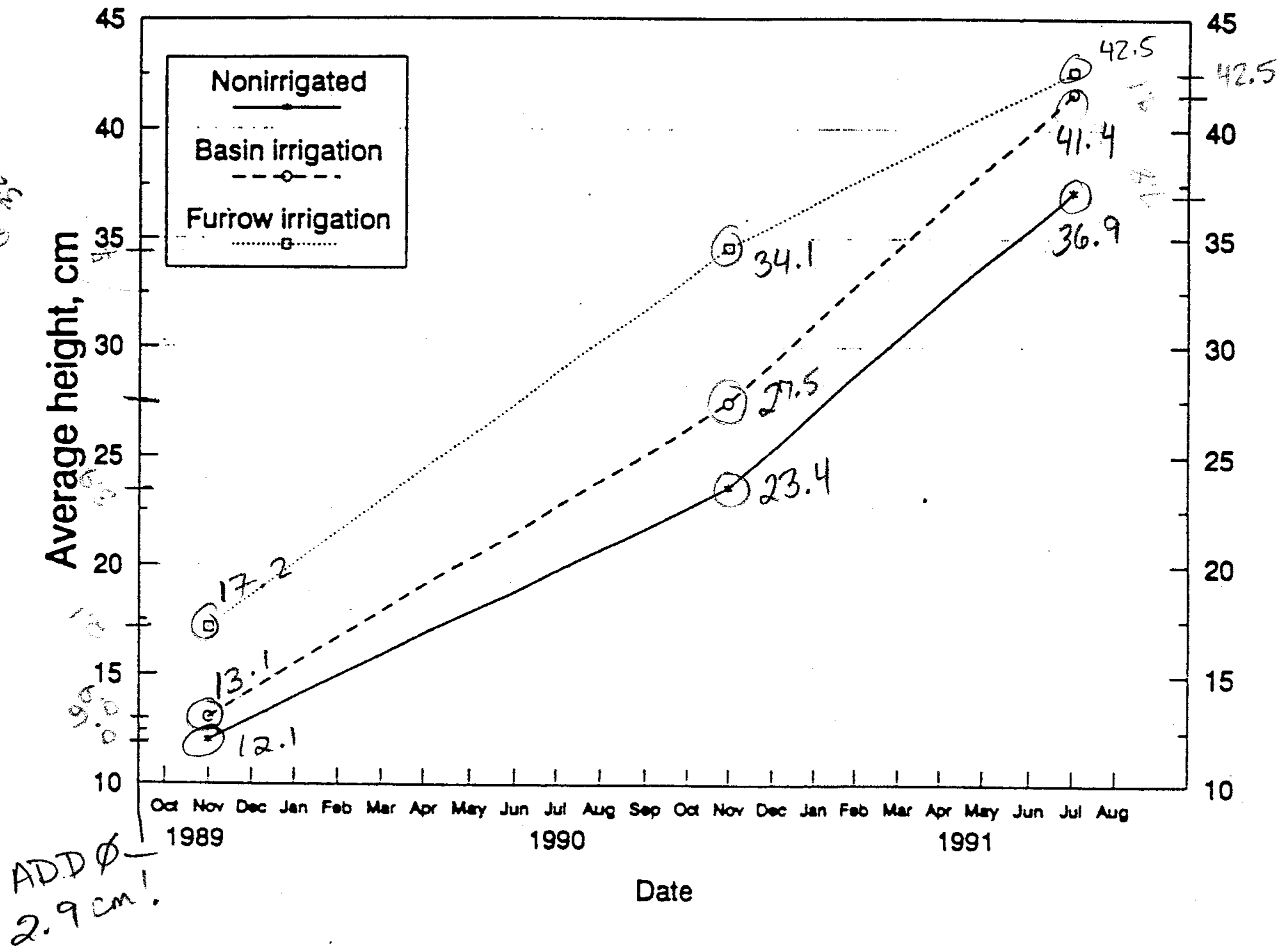


Figure 3-11. Average seedling heights by block and irrigation treatment in plot 2 at the Cosumnes River Preserve. Irrigation frequency was biweekly in the irrigated treatment during the summers of 1989 and 1990. Seedlings were not irrigated in 1991.



20 tree cm = 2.7 cm
1 cm = 20/2.7
= 200/27

Figure 3-12. Average seedling heights by irrigation treatment in plot 3 at the Cosumnes River Preserve. Seedlings grew from acorns planted December 1988. Water was applied to irrigated treatments once monthly only during the summer of 1989.



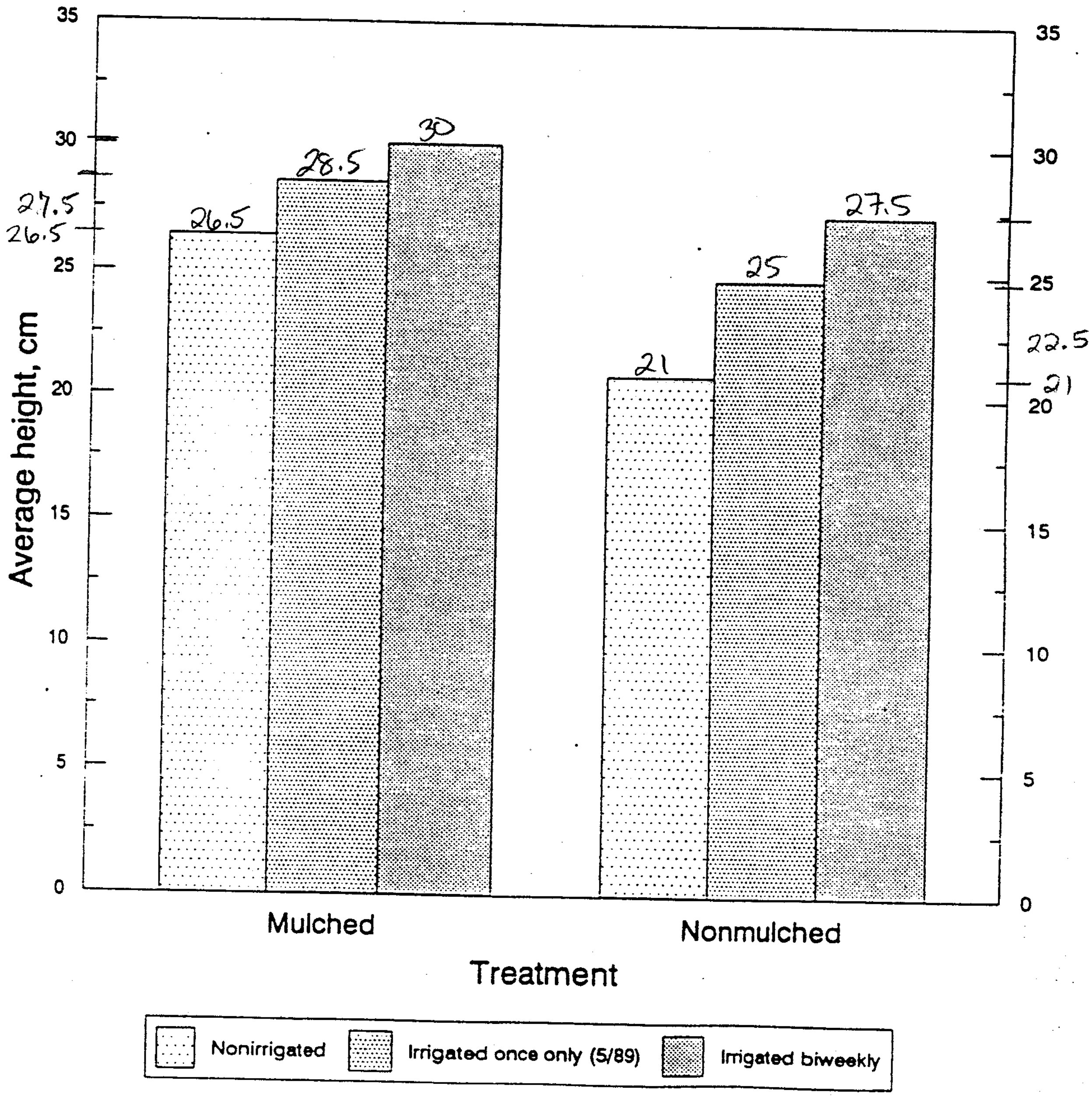
10 tree cm = 2.9 cm

1 cm = $\frac{10}{2.9}$ tree cm

Two Oaks

Figure 3-13. Average seedling heights by mulch and irrigation treatments in plot 4 at the Cosumnes River Preserve measured in July 1991. Seedlings grew from acorns planted in November 1989.

total avg = 26.4 (from JMP)
SE = 1.3



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Rows	Plot	MonthYear	N Rows	Mean(AvgHt1 (cm))	Std Err(AvgHt1 (cm))	Mean(AvgHt2 (cm))	Std Err(AvgHt2 (cm))
1	1	August 1990	4	50.25	4.60751198	.	
2	1	June 1991	4	52	3.36650165	.	
3	1	November 1989	4	33.75	3.94493346	.	
4	2	August 1990	4	.	.	33.5185185	9.15933739
5	2	June 1991	4	.	.	27.8703704	7.11679139
[illegible]	2	November 1989	4	.	.	13.9705882	2.66740546

Swiecki & Bernhardt 1991

Fig. 3-10 & 3-11

values entered into JMP

-Ingrid

	AvgHt	SE
Total (all plots & trts)	35	3.4

Rows	MonthYear	N Rows	Mean(AvgHt (cm))	Std Err(AvgHt (cm))
1	August 1990	8	41.8842593	5.70300122
2	June 1991	8	39.9351852	5.83747543
3	November 1989	8	23.8602941	4.33956236

Plots 1 & 2 = VC-N

Plot 3 = TF-W

Rows	Plot	MonthYear	N Rows	Mean(AvgHt (cm))	Std Err(AvgHt (cm))
1	1	August 1990	4	50.25	4.60751198
2	1	June 1991	4	52	3.36650165
3	1	November 1989	4	33.75	3.94493346
4	2	August 1990	4	33.5185185	9.15933739
5	2	June 1991	4	27.8703704	7.11679139
[illegible]	2	November 1989	4	13.9705882	2.66740546
~~7~~	~~3~~	~~July 1991~~	~~3~~	~~40.2666667~~	~~1.71302[illegible]2~~
~~8~~	~~3~~	~~November 1989~~	~~3~~	~~14.1333333~~	~~1.56027[illegible]~~
~~9~~	~~3~~	~~November 1990~~	~~3~~	~~28.3333333~~	~~3.11680035~~
10	4	July 1991	6	26.4166667	1.28722354

$\boxed{\text{VCN}}$

June '89 survival

Germination

June '89 survival			sites	June '89 % germ	Fall 1991 % surv. of germ.d
100%	—	Plot 1 —	216	87%	54% ; 98.
76%	—	Plot 2 —	+ 168	91%	98%
			384		

wt avg = 0.895 ⇒ 90%

~~Wt Avg =~~

Plot 1 wt = 0.5625

Plot 2 wt = 0.4375

wt avg	wt avg
.489375	.428906
+ .398125	+ .42875
0.8875	.85765
⇒ 89%	⇒ 86%
germ. June 1989	surv. of those germ. Fall 1991

* Part of this work done on Trailer Pad (Visitor Center) North, 1988

Ingrid's copy

MINIMUM INPUT TECHNIQUES FOR RESTORING VALLEY OAKS ON HARDWOOD RANGELAND: OVERVIEW AND PRELIMINARY MODEL

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INTRODUCTION

In many parts of its range, natural regeneration of valley oak *(Quercus lobata)* is insufficient to maintain current stand densities. Furthermore, many stands have been lost or degraded. Effective, low-cost techniques are needed to restock and restore valley oak in areas where natural regeneration is low or nonexistent.

This report summarizes the published information on natural and artificial regeneration of valley oak and our evaluations of past restoration projects. The information is integrated into a preliminary model of the conditions necessary to successfully restock valley oak. We have developed a set of guidelines for valley oak restocking based on this preliminary model, which is included at the end of the report.

EVALUATIONS OF PAST PROJECTS

To gain insight into the prospects for long-term survival in valley oak restocking projects, we visited and evaluated a number of valley oak restoration projects initiated more than three years ago. Candidate sites were identified from our review of the literature (Muick 1980, Oxford 1987, Pancheco 1987) and contacts with individuals involved in valley oak restoration. We located five sites which were more than three years old and for which most details regarding planting and survival were available. We also evaluated several projects initiated more recently. Sites selected for evaluation were distributed around the state to the extent possible. In addition, there was survival data for one experimental planting reported in the literature (Griffin 1971 and 1980) although the planting no longer exists.

Descriptions of the sites we reviewed are summarized in Tables 1-4. For each site evaluated, we compiled the following information:

- **Site characteristics.** Average rainfall, soil texture and depth were determined from soil survey maps published by the Soil Conservation Service. Notes on soil condition and topography were made at each site, and soil cores were examined at most sites to verify soil texture and depth. Average annual potential evapotranspiration (ET_O) for each site was determined from maps published by the California Department of Water Resources.
- **Planting and cultural details.** Planting dates, techniques, types and numbers of propagules used, irrigation methods and schedules, weed control practices, and types of protective devices used were identified through written records, interviews, and site inspections.
- **Survival and condition data.** First year survival data and damage and mortality factors noted to date were obtained from published reports or interviews. We rated the current survival, condition, form, height, and basal diameter of trees at each site.

DISTRIBUTION OF VALLEY OAKS

The terms *restoration* and *restocking* imply a return to a condition that existed previously. Therefore, in order to restore or restock valley oak stands, it is necessary to know whether valley oaks did or could have flourished in the area proposed for restocking. Restocking efforts are likely to require the fewest cultural inputs in areas that are the most favorable for valley oak by virtue of their soil type, climate, and topography.

Valley oak, as the common name implies, was historically most abundant on the deep alluvial soils of the Sacramento and San Joaquin valleys and the valleys of the Sierra foothills and Coast Ranges (Jepson 1910). In these deep loams, the valley oak attains the typical "weeping" form and reaches its greatest size. Valley oak was also common in the riparian forests, especially those along Central Valley river margins (Rossi 1980). However, it did not occur generally throughout the Central Valley (Griffin and Critchfield 1976).

Quercus lobata is not limited to valley floors. It is an important component of oak woodlands throughout the Coast Ranges and on alluvial terraces and hills surrounding the Central Valley. It also occurs in a number of upland plant communities and on the broader ridge tops of the south Coast Ranges (Griffin and Critchfield 1976). Although valley oak is not restricted to alluvial soils, it normally occurs only on soils which are classified as loams (Allen et al 1989).

The north-south distribution of valley oak extends from the Santa Monica Mountains in southern California (Swirsky 1986) to near Lakehead above the Sacramento River arm of Shasta Lake (Griffin and Critchfield 1976). Typical valley oak also occurs on Santa Cruz and Santa Catalina islands. Over most of its range, valley oak occurs at elevations of 610 m (2000 ft) or less, but ranges up to 1525 m (5000 ft) at Chews Ridge in Monterey County, and grows at 1700 m (5600 ft) in association with Jeffrey pine in the Tehachapi Mountains.

In southern Monterey County a few valley oaks reportedly grow within a mile of the coastline (Griffin and Critchfield 1976). However, Jepson (1910) noted that valley oak "shows a strong dislike for valleys facing the ocean". This may be related to its sensitivity to wind-borne sea salt aerosols, which may damage valley oaks located as far as 60 km (37 mi) from the coast (Ogden 1980).

CHARACTERISTICS OF VALLEY OAK ACORNS AND SEEDLINGS

Valley oak reproduces almost entirely by seed. Only young trees are capable of regenerating through stump sprouts. Hence, the fate of acorns and seedlings is of critical importance in regeneration of valley oak. Valley oak is a very prolific seed producer, although the size of the acorn crop varies between trees, and is variable from year to year in any given location. The acorns themselves may be quite variable in size and shape between different trees.

Good germination rates for valley oak acorns have been reported repeatedly (Griffin 1971, Matsuda and McBride 1986, Swirsky 1986). Valley oak acorns have no constitutive dormancy and are ready to germinate as soon as they fall from the tree, although the time required for 100% germination varies by the source tree from which the acorns are gathered (Griffin 1971, Matsuda and McBride 1986). Occasionally, acorns will be seen germinating on the tree before they fall (Griffin 1971). Typically, emergence rates for acorns planted in field situations are over 80% (Table 2, McCreary 1989).

Following germination, which may occur soon after the soil is wetted by fall rains, the young seedling produces a substantial taproot. Matsuda and McBride (1986) planted germinated valley oak acorns into a loose organic soil to observe seedling root and shoot development. Seedlings with shoots only

2 cm (0.8 in) long had already developed roots 37 cm (14.5 in) long. By the time that valley oak seedlings had fully expanded leaves, the main taproot had attained a length of 86 cm (34 in).

This long, stout taproot confers some survival advantage to valley oak seedlings. Since most food reserves are stored in the roots, seedlings are often able to resprout after the loss of their shoots due to desiccation, browsing, or other causes. Furthermore, in deep, noncompacted soils, the long valley oak taproot may be able to exploit soil moisture reserves that are not depleted by annual grasses and forbs.

At each of the restocking sites, seedlings displayed a great deal of variation in growth rate, plant form, and vigor. Some of the observed variation in height was due to the fact that many seedlings had formed multiple leaders or trunks (Table 4). Variation between individual seedlings may be associated with the initial condition of the propagule planted, genetic differences in growth rate and adaptability, microsite variation in environmental or soil factors, and/or damage by various agents. Whether by their nature or location, some seedlings appear to have a better chance of surviving to maturity than others.

Most of the restocking sites we visited reported good first year survival for transplants and good germination rates for acorns (Table 4). However, in most locations, survival had dropped to less than 50% after 3 or more years, irrespective of first year survival. The best long-term (5 year) survival was seen at Lopez 1 (Table 4), a small planting that has been intensively managed and regularly irrigated. Although high rates of seedling establishment may be obtained through intensive effort, in most low-input projects it is probably more efficient to simply increase planting density enough to offset the expected attrition. This should allow natural selective pressures to operate and result in the survival of the best-adapted or best-situated trees.

FACTORS LIMITING NATURAL AND ARTIFICIAL REGENERATION OF VALLEY OAK

Despite the fact that acorns germinate readily when well-covered with litter or soil, natural reproduction is often exceedingly scanty. This fact was noted near the turn of the century by Sudworth (1908), who thought that poor seedling establishment was due to the fact that very few acorns became buried under the prevailing cultural conditions. Since then, various studies have shown that a variety of agents can deplete the acorn supply or contribute to poor acorn germination. After germination, additional factors may limit the survival of valley oak seedlings in rangeland settings.

We have identified the principal factors known to limit natural and artificial reproduction of valley oak from our review of the literature and past restocking projects. These factors are summarized below. We also discuss techniques that have been or could be used to overcome these limitations.

Physical factors affecting acorn viability

Valley oak acorns, like acorns of other oaks that have no inherent dormancy, lose viability as they lose moisture. If *Quercus* acorns are collected when they still show some green color, they will be respiring and their moisture content will be in excess of 50% (Gordon and Rowe 1982). Griffin (1971) allowed valley oak acorns to air dry for 2 months during winter in a laboratory in the Carmel Valley and found that they still germinated well when placed in plastic bags at favorable temperatures and moisture conditions. However, the actual moisture loss under these conditions was not stated. With acorns of the closely related blue oak (*Q. douglasii*), one month of air drying resulted in a 25% moisture loss and a complete loss of viability (McCreary 1989).

Since the rate of moisture loss will vary with temperature and relative humidity, storage conditions determine how fast acorns lose moisture. The objective in storing acorns is to slow down respiration while maintaining moisture at a relatively high level. This is most commonly accomplished by placing acorns in plastic bags and holding them in cold storage at temperatures slightly above freezing. Even under these storage conditions, acorns can only be stored for a limited time period, since they will eventually germinate. The emerged roots are susceptible to desiccation, breakage, and attack by various fungi, resulting in a loss of viability.

Storing acorns in the soil via early planting may provide an alternative to storing acorns in bulk for extended periods. Since the surface temperature of soils exposed to direct sunlight may be well above the ambient air temperature, acorns that remain exposed on the soil surface for an extended period will likely lose viability. However, a more favorable environment for acorn survival is provided if acorns are buried and covered with a layer of organic mulch. Mulch significantly reduces soil temperatures and helps conserve soil moisture (Brady 1974). Furthermore, the relative humidity of soil air is essentially maintained at 100% at soil water potentials greater than about -3 MPa (-30 bars), which is well below the wilting point for most plants. A mulched soil provides high humidity and moderate temperatures which should allow buried acorns to survive for weeks or months until sufficient moisture is available to permit germination.

Acorn consumption by insects and microorganisms

The larvae of two insects, the filbertworm and the filbert weevil, commonly infest valley oak as well as other oak acorns (Brown 1980). Both of these insects infest acorns while they are attached to the tree, but continue feeding and developing after the acorn has dropped. These larvae bore through the acorn endosperm, which results in a decrease in acorn viability (Knudsen 1987, Griffin 1980). Although acorns may sustain some damage and still germinate, damage to the acorn embryo will reduce the food reserves of the young seedling, and may reduce seedling vigor. Acorns that are not destroyed by insect feeding may still be rendered nonviable by decay organisms that infect through wounds made by insects.

Insect-infested and diseased acorns tend to drop earlier than sound acorns (Swiecki 1990). Therefore, acorns picked from the tree will normally have a lower percentage of insect infestation than those collected from the ground. Also, since insect exit holes are generally indicative of significant internal acorn damage (Swiecki 1990), discarding acorns with exit holes will improve the overall germination rate of an acorn lot.

Acorn consumption by vertebrates

Acorns serve as either a major or supplemental source of food for many vertebrate animals that utilize oak woodlands. In California, at least 30 species of birds (Verner 1980) and 37 species of terrestrial mammals (Barrett 1980) reportedly include acorns in their diets. Large grazing animals, especially deer, pigs, and cattle (de Nevers and Goatcher 1990, Duncan and Clawson 1980, Rossi 1980) may consume a high percentage of the acorn crop as it falls. Small mammals may also be important acorn consumers, although their relative significance apparently varies between locations. Ground squirrels (*Spermophilus beecheyi*) are frequently cited as important acorn consumers in oak planting projects and experiments. Other rodents that have been reported to prey on planted acorns include gophers, wood rats, mice, voles, and rabbits (Knudsen 1987, Griffin 1976, Adams 1987).

Acorn foraging by some vertebrates may not be completely detrimental to valley oak reproduction. Animals that bury acorns, including jays, magpies, and squirrels, may actually have a role in aiding oak regeneration (Griffin 1971). Buried acorns are less subject to desiccation, as noted above, and are less likely to be consumed by deer or other large vertebrates. Many of these cached acorns may not be consumed, especially in bumper crop years, and will effectively be planted. Acorn woodpeckers also store large quantities of acorns for later use, but because they are stored above ground in granary trees, they are largely unavailable for reproduction (Koenig 1980).

For restoration projects, it is desirable to determine the potential for acorn loss prior to planting, and adjust planting specifications accordingly. Burying acorns in widely spaced sites to a depth of approximately 5 cm (2 in) provides a significant degree of protection against grazing animals, birds, mice, and low populations of other rodents (Griffin 1971, McCreary *personal communication*). However, if populations of acorn consumers are high, the planting is especially dense, or if some loss of acorns cannot be tolerated, protective caging (discussed below) or other vertebrate control measures will be required.

Seedling herbivory

Agents that attack emerged valley oak seedlings fall into two general categories: those which feed primarily on the acorn, and those which feed primarily on the seedling. The first category includes several of the acorn-eating vertebrates discussed above. These animals uproot young seedlings in their efforts to get at the attached acorn. Ground squirrels are the most serious in this regard, although scrub jays and other vertebrates may also cause damage of this type. An unprotected planting of valley oak transplants was completely destroyed in less than a month by high populations of ground squirrels in Cheseboro Canyon (Tables 3 and 4). Protective caging above and below ground and the use of older planting stock without attached acorns have been used to reduce damage of this type.

The second category of seedling herbivores feed primarily on the shoots, leaves, or roots of the developing seedling. The severity of damage may range from inconsequential to lethal. Cattle and deer often browse heavily on the foliage and young shoots of various oaks, including valley oak, and have limited the growth of seedlings at several of the restocking sites we examined. Although a vigorous young valley oak may withstand the loss of most of the shoot by resprouting from the base, repeated browsing of the shoot can deplete the seedling's energy reserves and eventually result in its death. Sublethal levels of browsing pressure severely reduce seedling growth, and saplings may remain in a highly-branched, shrubby form for many years (Griffin 1971, Rossi 1980). In the Pope Valley, we have observed that cattle use the larger branches of valley oak shrub-saplings to scratch themselves, causing additional damage to the tallest shoots. Some of these shrub-like saplings may eventually grow to a height that allows them to escape browsing, and finally develop into a tree form.

Various small mammals may also be included in this second category of seedling herbivores, but the significance of their impact on seedling growth and survival is more variable from location to location. For example, while Griffin (1980) reported extensive seedling destruction by gophers in the Carmel Valley, others (Knudsen 1987, Bush and Thompson 1989) found that seedling losses due to gophers were relatively minor. Gophers were not a limiting factor at any of the restocking sites we evaluated, and we have observed valley oak saplings growing in the middle of active gopher colonies. It is unclear whether gophers aggressively seek out valley oak seedlings, but it is obvious that they pose a problem in some areas. Although mice and voles have also been blamed for seedling and acorn losses (Knudsen 1987), there is not enough information to make a definitive statement about the potential destructiveness of these small rodents to valley oaks.

Various researchers have observed defoliation of young oak seedlings by grasshoppers or caterpillars. These problems have been most intense in experimental trials where seedlings are grown very close together in small plots and where the ground around the seedlings has been cleared of vegetation. These cultural conditions may favor damage by migrating insects such as grasshoppers. Our survey of restocking projects indicated that defoliation by grasshoppers or other insects was not a significant problem in past regeneration efforts. Heavy infestations of scale (mostly oak pit scale, *Asterolecanium* sp.) were observed on seedlings at several sites, but the effect of these infestations on seedling growth and survival is not known.

Soil moisture

Competition for soil moisture may be an important factor limiting natural regeneration in many areas. Over the past two centuries, the species composition of the herbaceous layer in California's oak woodlands has been dramatically altered. Introduced Mediterranean annual grasses and forbs have largely replaced native perennial bunchgrasses in the oak understory (Gordon et al 1989). There is experimental evidence to support the widely-held belief that introduced annual grasses and taprooted forbs deplete soil moisture more rapidly than native perennial grasses (Danielsen 1990, Gordon et al 1989).

Competition for soil moisture can reduce valley oak seedling growth and survival. Knudsen (1987) noted that survival of natural valley oak seedlings increased as grass density decreased. Adams et al (1987) found that increased competition from weeds responding to fertilizer applied at planting resulted in significantly less seedling emergence than occurred in non-fertilized controls. In various trials, Adams (*personal communication*) obtained greater survival and growth of valley oak seedlings when annual weeds were controlled with herbicides. In greenhouse experiments, Danielsen (1990) found that the growth of valley oak seedlings was depressed more by the introduced annual grass *Avena fatua* than by the native perennial bunchgrass *Stipa pulchra*, but valley oak seedlings grown without any competing vegetation grew the most. Griffin (1971) obtained 100% seedling establishment from valley oak acorns planted in cleared plots during a drought year (1967-68), while all seedlings died by May in adjacent grassy plots (Tables 3 and 4).

At many of the restocking sites we visited, competing vegetation was reported to limit survival and growth of seedlings. Managers at Cheseboro Canyon and Lopez Lake noted that tall growth by winter annuals completely hid young oak seedlings by spring. However, even though competition for soil moisture may be more intense in the presence of annual grasses, it does not always preclude natural regeneration of valley oak. We have observed unassisted valley oak reproduction at various locations in northern California in the presence of introduced annual weeds.

Competition for soil moisture by herbaceous vegetation is not the only factor that limits available soil water. The severity of moisture deficit depends on the interaction between:

- **competing vegetation**, including species composition and density;
- **water input**, including precipitation, natural surface and subsurface flow, and irrigation;
- **soil characteristics**, including soil type, water-holding capacity, depth, and compaction;
- **site factors**, including potential evapotranspiration (ET_O), slope, aspect, and shading.

The degree to which soil moisture limits valley oak reproduction may be quite variable from location to location. Therefore, it may be possible to adjust the intensity of weed control and moisture conservation inputs to account for the degree of soil moisture deficit that is anticipated at the site. For example, soil moisture is not likely to be critically limited at a site such as Windsor, where the soil is a deep clay loam and annual rainfall is high relative to annual ET_O (Table 2). In contrast, at Lopez Lake, annual ET_O is far in excess of annual rainfall and soil water holding capacity is low due to sandy soil texture. Differences in soil moisture availability may in part explain why two year old seedlings at Windsor are virtually as tall as five year old seedlings at Lopez Lake (Table 4).

CULTURAL INPUTS USED IN ARTIFICIAL REGENERATION

Transplanting versus direct seeding

Transplants have frequently been used in restocking projects (Table 3). Transplants have several advantages:

-their availability is not dependent on the current year's acorn supply, which may range from abundant to nearly nonexistent;
-their viability and condition can be assessed at the time of planting;
-they are visible immediately after planting.

However, transplants also have several disadvantages relative to direct-seeded acorns:

-the dominance of the taproot is usually destroyed, and root form may be poor, rendering the seedlings less drought tolerant;
-transplants require space for propagation and care in the nursery, and so are more costly to produce;
-transplants are more difficult to store and transport than acorns;
-transplants available commercially are often not derived from local seed sources unless special provisions are made far in advance;
-soil-borne pathogens or insect pests may be introduced with the transplants;
-transplants require more effort and care in planting, and normally require some irrigation.

The amount of care required for successful establishment generally increases with the size of the nursery stock used. Of the plantings we reviewed, the largest planting stock was used at the Bicentennial Grove site (Table 3). This project also had extremely poor survival in its first two growing seasons, due to the use of rootbound trees, poor planting technique, late planting date, and inadequate irrigation. However, the oldest project we reviewed, John Brown Pond (Table 3), was successfully established with container-grown trees.

In an experimental plot, McCreary (*personal communication*) found that after two years, direct seeded acorns outgrew transplanted seedlings. At two planting sites along the Sacramento River, direct-seeded valley oaks from pregerminated acorns were more vigorous 6 months after planting than transplants (Sid Jones *personal communication*). Most of the planting sites we visited were restocked with transplants (Table 3), and only one of the extant direct-seeded planting sites (Lopez 2) was more than 2 years old.

Although it would appear that valley oaks can be successfully established from either transplants or direct-seeded acorns, at this point there is not enough evidence to indicate a distinct survival advantage for one method over the other. Since there is little evidence to suggest that transplanting provides enough benefits to outweigh its liabilities, we recommend direct planting of acorns as the preferred method for restocking valley oaks in most low-input situations.

Seedling Protection

Various types of exclosures have been used in oak restocking projects to reduce acorn and seedling destruction caused by herbivores. Construction and installation of these exclosures add significantly to the cost and time required for restocking. To minimize costs, seedling protection should be tailored to exclude the particular herbivores present at the planting site. Furthermore, if populations of herbivores are quite low or their distribution is spotty, it may be possible to forego protection entirely or restrict it to certain areas. The advantages and disadvantages of the most commonly used exclosures are reviewed below.

<u>*Lightweight seedling protectors*</u>

Planting collars and plastic seedling protectors have been used in some projects to protect oak seedlings from herbivores. The planting collar consists of a window screen cylinder attached to a bottomless, plastic one-quart container (Bush and Thompson 1989). Acorns are planted within the plastic container, which is buried so that its top is nearly level with the soil surface. When properly constructed, this type of exclosure may be effective against some larger insects, birds, voles, rabbits, and deer. However, planting collars will not protect seedlings against aggressive burrowing animals such as ground squirrels and gophers, and are easily destroyed by cattle. Insect protection is only provided when the screen is completely closed, and seedlings can be defoliated when grasshoppers or other insects become trapped inside of these screen cages.

Planting collar screens are seldom made taller than 45-60 cm (18-24 in) due to lack of structural support. Closed screens must be opened to prevent deformation of the shoot once seedlings reach the top of the screen, which may occur within the first growing season. This requires additional labor, eliminates any possible insect protection, and exposes the growing tip to herbivory.

The performance and limitations of various types of plastic mesh or screen seedling protectors are similar to that of the planting collar. Plastic seedling protectors are generally easier to install, since they do not extend below the soil surface. Most are made of photodegradable plastic to eliminate the need for disposal. However, only closed protectors made of fine-meshed materials are likely to provide any protection against insects.

<u>*Individual seedling/sapling cages*</u>

Various types of cages have been constructed to protect acorns and seedlings from vertebrates. In areas where ground squirrel or gopher activity is intense, adequate protection has been obtained by enclosing the acorns or seedlings in a poultry netting cylinder that is buried to a depth of at least 45 cm (18 in) and extends at least an equal distance above ground. Taller poultry netting cylinders also provide protection against browsing by deer, but are not normally strong enough to be used where cattle are present. Taller cylinders normally require a rod or post for support. The materials used to construct these cages are relatively inexpensive, but assembly and installation are moderately labor-intensive.

Single tree exclosures used to protect against cattle must be constructed quite sturdily. A common design employs three metal fence posts and field fencing wire. When properly constructed, these exclosures are reasonably effective, but labor and material inputs are rather high. We are currently testing a more economical exclosure design which uses a single fence post to support a semi-rigid wire mesh cylinder. Provided that they are tall enough, exclosures designed to protect against cattle are normally effective against deer as well.

<u>*Fenced areas*</u>

The value of protection against cattle browsing can often be seen by observing the density and size of valley oak seedlings and saplings growing along fence lines or just outside of pasture fences. This empirical evidence suggests that excluding cattle and/or deer from large areas may sometimes be sufficient to allow natural regeneration to proceed.

However, the removal of grazing pressure can lead to changes in the herbaceous layer and increased competition for soil moisture. At the Wantrup Sanctuary and Pepperwood Reserve, exclusion of cattle from some fields has enabled harding grass (*Phalaris tuberosa* var. *stenoptera*) to proliferate.

This aggressive introduced perennial grass has formed dense and nearly pure stands in some areas, and poses an obstacle to both natural and artificial regeneration.

Although cattle can be excluded from large areas with simple and relatively inexpensive fencing, the same is not true for deer. Fences intended to exclude deer must generally be at least 1.8 m (6 ft) tall and made of mesh or closely spaced wires (Salmon and Lickliter 1984). The single-tree deer exclosures are likely to be less costly than deer-resistant fencing for most restoration projects.

Moisture conservation and augmentation

Irrigation

Most of the restocking efforts we visited used some summer irrigation, at least for the first year after the oaks were planted or transplanted. Commonly, hand watering with hoses or buckets was used. Several significant drawbacks were identified where hand watering was used:

-irrigation schedules are often irregular, and do not necessarily correspond with water demand;

-irrigation operations are usually time-consuming and labor-intensive;

-water application is usually inefficient, with excessive losses due to evaporation and runoff, resulting in relatively shallow penetration.

The Cosumnes River Preserve has used a drip irrigation system (Table 3). Compared with hand watering, drip irrigation systems are less labor-intensive to operate, make irrigation scheduling easier, and allow better percolation of water deep into the soil profile. However, time and labor are required to install and maintain a drip irrigation system, and the cost of materials can be high, especially if the water source requires extensive filtration. If cattle are present on the site, drip lines must be buried, which increases costs substantially.

Since irrigation requires a substantial commitment of resources, it is desirable to determine whether this particular input is necessary at a given location. However, there are relatively few studies that address this question directly. It is our premise that on most favorable sites, irrigation should not be necessary to establish seedlings from direct-seeded valley oak acorns. Results from several experiments we initiated in 1989 should help clarify what benefit is derived from irrigation under several different conditions.

Control of competing vegetation

As noted above, removal or control of competing herbaceous vegetation is a means of conserving soil moisture and may eliminate the need for irrigation. McCreary (*personal communication*) found that no irrigation was necessary to establish valley oaks from seed when soil augering and complete weed control were used. Weed control has been accomplished with hand weeding, tillage, mowing, herbicides, and plastic or organic mulches in various projects. While each method has advantages and drawbacks, relative cost and efficacy of the various methods has not been compared for valley oak establishment.

Although cattle affect oak seedlings adversely by browsing shoots and compacting soil, cattle grazing can substantially reduce weed competition. If oak seedlings are protected and grazing is avoided when soils are wet, it may be possible for cattle and valley oak restocking to coexist.

Shading and mulching

When scalping is used to control weeds, the bare, unshaded soil around the seedling is subject to water loss due to evaporation. Mulching with organic or synthetic materials helps conserve soil moisture by reducing surface evaporation and suppressing weed growth. In addition, it serves to moderate soil temperatures (Brady 1974) which may have a beneficial effect on root growth. We are currently conducting experiments to evaluate the effect of mulching on seedling emergence and survival.

Screen cages, discussed above, may reduce evapotranspiration by providing shade and reducing wind velocity in the immediate vicinity of the seedling. These effects could benefit transplants by diminishing the "transplant shock" associated with their limited root systems. However, we did not find any studies that specifically addressed the potential benefits of shading in establishing valley oak seedlings.

Table 1. Location of valley oak restocking sites.

Site	Location/ Nearest City	County
Bicentennial Grove	American River Parkway/ Sacramento	Sacramento
Cheseboro Canyon[1]	Santa Monica Mountains Nat. Rec. Area/ Agoura Hills	Ventura
Cosumnes 1	The Nature Conservancy Cosumnes River Preserve/ Galt	Sacramento
Hume Grove	Peña Adobe Open Space/ Vacaville	Solano
John Brown Pond[2]	Wastewater Reclamation Facility/ Santa Rosa	Sonoma
Lopez 1 and 2[3]	Lopez Lake Recreation Area/ Arroyo Grande	San Luis Obispo
Savannah and Woodland plots[4]	U.C. Hastings Reservation/ Carmel Valley Village	Monterey
Windsor Creek	Windsor Creek/ Windsor	Sonoma

Table 2. Environmental and soil characteristics of restocking sites.

Site	Average Annual ET_o (cm)	Average Annual Rainfall (cm)	Soil Texture	Soil Depth (cm)	Natural Regeneration in Vicinity
Bicentennial Grove	132	46	sand	> 61	no
Cheseboro Cyn	129	36-51	clay loam	> 152	no
Cosumnes 1	119	38-48	clay loam	> 61	yes
Hume Grove	124	51-76	clay loam	64-102	yes
John Brown Pond	107	76-102	loam	> 152	no
Lopez 1 and 2	111	38-51	loamy sand	81	no
Savannah plot	121	51	sandy to clay loam	45	no
Woodland plot	121	51	sandy to sandy clay loam	70	yes
Windsor Creek	104	76-114	silty clay loam	> 201	yes

[1]Pancheco 1987
[2]Muick 1980
[3]Oxford 1987
[4]Griffin 1971, 1980

Table 3. Cultural history of restocking projects.

Site	Date Planted	Planting Stock	Protection Above/ Below Ground	Summer Irrigation	Weed Control
TRANSPLANTS					
John Brown Pond	4/79	1 gal, 5 gal	stakes/none	1st year by hand	mowing
Lopez 1	Fall 84	1 yr seedlings	1" mesh/1" mesh	all years by hand	scalping, mowing
Cheseboro Cyn 1	3/85	3 mo seedlings	1" mesh/1" mesh	2 yrs by hand	scalping, 2 yrs
Cheseboro Cyn 2	3/86	3 mo seedlings	1" mesh/1" mesh	1st yr by hand	scalping, 1st yr
Cheseboro Cyn 3	6/86	6 mo seedlings	none/none	--	--
Hume Grove	12/86	1 gal	6" mesh & posts/none	by hand	none
Windsor Creek	11/87	1 yr liners	screen/plastic collar	1st year by hand	landscape fabric
Bicentennial Grove	4/88	15 gal	none/none	by hand	scalping, mulch
ACORNS					
Woodland clear	12/67	germ. acorns	wire fencing/½" mesh	none	scalping
Savannah clear	12/67	germ. acorns	wire fencing/½" mesh	none	scalping
Savannah grass 1	12/67	germ. acorns	wire fencing/½" mesh	none	none
Savannah grass 2	12/68	germ. acorns	wire fencing/½" mesh	none	none
Lopez 2	12/85	acorns	1" mesh/1" mesh	years 1, 3, 4 by hand	scalping, mowing
Cosumnes 1	1/88	acorns	screen/plastic collar	drip or by hand	scalping

Table 4. Survival and growth of valley oak seedlings at restocking projects.

Site	1st Year Survival	% Survival...	After —Years	% With Single Leader	Height (cm) Average	Height (cm) Std Dev	Basal Diameter (cm) Average	Basal Diameter (cm) Std Dev
TRANSPLANTS								
John Brown Pond	95%	41.5%	10	46%	370	120	10.7	5.4
Lopez 1	--	89%	5	0%	49	20	0.8	0.4
Cheseboro Cyn 1	100%	20%	4.5	4%	66	32	1.1	0.5
Cheseboro Cyn 2	60%	20%	3.5	13%	42	26	0.6	0.3
Cheseboro Cyn 3	0%	--	--	----	----	----	----	----
Hume Grove	70%	43%	3	18%	48	18	0.7	0.3
Windsor Creek	87%	--	--	19%	40	18	0.6	0.1
Bicentennial Grove	50%	32.9%	1.5	100%	260	60	2.4	0.5
ACORNS								
Woodland clear	100%	88%	3	----	----	----	----	----
Savannah clear	100%	31%	3	----	----	----	----	----
Savannah grass 1	0%	--	--	----	----	----	----	----
Savannah grass 2	68%	68%	2	----	----	----	----	----
Lopez 2	99%	33%	4	21%	34	17	0.5	0.1
Cosumnes 1	>90%	--	--	----	----	----	----	----

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PRELIMINARY GUIDELINES FOR VALLEY OAK RESTOCKING IN RANGELAND SETTINGS

Our review of the literature and past planting projects indicates that seedling mortality is most commonly the result of water deficit and/or damage by vertebrates. However, these lethal stresses are achieved under a variety of different circumstances, which require different remedial actions.

We have summarized the above information into the following conceptual model for restocking valley oaks in rangeland (non-urbanized) settings. The model is preliminary at this stage, and information from experiments currently in progress will be used to amend the model as needed. The model is presented as a checklist of the major factors which limit valley oak establishment. To use the checklist, note the recommendation that matches your answer to each question about characteristics of the proposed restocking site. The resulting list of recommendations will indicate the suitability of the site for valley oaks, and the minimum inputs required for restocking.

The site factors covered in the checklist are grouped in the following categories:

- A - Climate factors
- B - Natural regeneration
- C - Soil factors
- D - Weed competition
- E - Vertebrate herbivory

General recommendations for planting are listed in section F.

Section A. Climate factors

A1. Are valley oak trees now present or were they historically present in the immediate vicinity of the proposed planting site?	YES	AA. If the site has not been substantially drained, graded, flooded, or otherwise altered, it should be favorable for valley oaks. (Go to B1)
	NO	AB. The site may not be favorable for valley oaks. (Go to A2)
A2. Is the site located: - within the known natural range for valley oak (see attached map), - at an elevation of less than 1830 m (6000 ft) in S. Calif. or 1525 m (5000 ft) in N. Calif., **and** - in an area with average annual rainfall of at least 25-35 mm (15-20 in)?.	YES	AC. The site <u>may</u> be suitable for valley oak. Planting will be required; see section F. Proceed with caution, giving special attention to soils recommendations. (Go to C1)
	NO	AD. It is likely that the site is not suitable for valley oaks. Consider using a different tree species or location. Any valley oak planting should be considered experimental. Continue through guidelines from C1 if planting is still contemplated.

Section B. Natural regeneration

B1. Are there any natural seedlings or saplings at the site?	YES	BA. The site is probably favorable for both natural regeneration and planting, but moisture stress or herbivory may be constraining seedling and sapling growth. It may be possible to restock the stand without planting by conserving and assisting existing seedlings and saplings. (Go to B2)
	NO	BB. Conduct a very careful inspection to be sure that no seedlings are present. Young seedlings are very small, and are difficult to see among high weeds in early spring or when their leaves turn brown, which may occur by midsummer. If no seedlings are found following an intensive search, seedling failure may be due to consumption of acorns and/or seedlings by animals, and/or lack of moisture. Alleviating these constraints may allow natural seedlings to become established. Alternatively, planting may be used to restock the stand. See section F. (Go to C1)
B2. Is the density and distribution of existing natural seedlings and saplings adequate for your restocking goals? (You can evaluate density and distribution by prominently flagging seedlings and tallying the number per unit area.)	YES	BC. Restocking can probably be achieved with existing seedlings/saplings. Inspect existing seedlings/saplings for symptoms of moisture stress and/or damage by herbivores to determine whether either of these factors appears to be limiting growth or survival. (Go to D1)
	NO	BD. Low numbers of seedlings may be due to consumption of acorns and/or seedlings by animals, and/or lack of moisture. Alleviating these constraints may increase natural seedling recruitment to acceptable levels. Alternatively, planting may be used to increase the stand density. See section F. (Go to C1)

Section C. Soil factors

C1. What is the soil texture? (Check a soil map, and verify by coring or using a shovel to sample soil. Consult with a specialist or have soil tests run if you are uncertain.)	SANDY LOAM TO CLAY LOAM	CA. This indicates the site has good potential as a restocking site, since native stands of valley oak are normally found on these soil types. However, soil types may vary over short distances, so be sure that the planting sites are all located in these favorable soil types. (Go to C2)
	LOAMY CLAY TO CLAY	CB. These soils may be unsuitable for valley oaks if they are poorly drained or compacted. If the soil has good secondary structure and is not subject to ponding, the site may be favorable. Care should be taken to preserve and enhance soil structure. In particular, avoid working the soil when wet. (Go to C2)
	SAND TO LOAMY SAND	CC. Unless permanent ground or surface water is present, soil may be too droughty for good valley oak growth. If no valley oaks are in the vicinity, the site may not be suitable for them. If valley oaks are in the vicinity, evaluate their condition. The site may be marginal for valley oaks, and it may be difficult to establish seedlings. If planting is contemplated, supplemental irrigation will probably be necessary until trees are well established, and mulching is highly recommended. Consider using a tree species better adapted to the site or relocating the project to a site more favorable for valley oak. (Go to C2)
C2. Is the approximate depth of the soil at least 60-90 cm (2-3 ft)?	YES	CD. Soil depth will probably not be a major factor limiting valley oak growth. (Go to C3)
	NO	CE. Limited soil depth may constrain valley oak establishment and growth, especially on sandier soils. Plant in microsites where soil is deeper, relocate the project to a more favorable site, or use a tree species better adapted to the site. (Go to C3)
C3. Is the soil moderately or severely compacted, or is a hardpan present? (Test by probing or coring the soil to approximately 60 cm [2 ft].)	YES	CF. Some soil preparation may be required to permit good taproot growth, especially if soils are clayey. Seedling establishment may be more successful if planting holes are augered or soil is ripped to a depth of 60-90 cm (2-3 ft). (Go to C4)

	NO	CG. Little or no soil preparation may be needed to obtain good seedling establishment. (Go to C4)
C4. Is the soil high in soluble salts or boron?	YES	CH. Although evidence is limited, valley oak seedlings are likely to be intolerant of salinity and boron. If salinity and boron cannot be effectively lowered through leaching, consider relocating the project to a more favorable site or using a better adapted tree species. (Go to D1)
	NO	CI. Salinity and boron should not limit valley oak establishment. (Go to D1)

Section D. Weed competition

D1. What is the density of herbaceous vegetation?	HIGH	DA. Weed competition will probably limit seedling growth and survival on most sites. Weed competition should be reduced using an appropriate method to ensure success of the restocking effort. Direct weed removal, herbicide treatment, and use of organic mulch or synthetic weed control fabric are the principle weed control options. (Go to E1)
	MODERATE	DB. Weed competition may limit seedling growth and survival, particularly on sandier soils or in hotter, drier sites. If natural seedling or saplings are present, you may be able to see whether weed competition is constraining natural regeneration. Unless soil moisture is abundant, reducing weed competition around seedlings should improve oak growth and survival. General weed control strategies are listed above at DA. (Go to E1)
	LOW	DC. If soil texture, depth, and condition are favorable, weed competition may not pose a serious constraint. If the site is especially harsh due to poor soils or other factors, weed control may improve growth and survival enough to justify this additional input. General weed control strategies are listed above at DA. (Go to E1)

Section E. Vertebrate herbivory

E1. Are livestock grazed on the site?	YES	EA. Seedlings may need to be protected from livestock browsing. (Go to E2)
	NO	EB. Protection against livestock is not required. (Go to E3)
E2. What is the intensity of grazing?	MODERATE TO HEAVY GRAZING	EC. Seedlings and saplings will require protection from livestock for successful establishment. Options include severely reducing or eliminating grazing, or caging individual seedlings/saplings. (Go to E3)
	LIGHT GRAZING	ED. If natural seedlings are present, look to see if they are being browsed. Browsed seedlings/saplings are very bushy and often quite woody for their height. If damage is significant, protection from livestock will be necessary. Eliminate grazing until trees are above browse level or cage individual seedlings/saplings. (Go to E3)
E3. Are there high populations of deer in the area? (Look for evidence of deer browsing on low branches of trees or on natural seedlings/saplings.)	YES	EE. Although deer browsing seldom kills oak seedlings, their growth may be severely stunted for an indefinite period. Install a deer-proof fence around the site or cage individual seedlings/saplings. Note that cattle-resistant cages will also protect against deer. (Go to E4)
	NO	EF. If deer are uncommon in the area and other sources of browse are available, protection against deer will not be necessary. (Go to E4)
E4. Are there moderate to high populations of ground squirrels in the vicinity?	YES	EG. Ground squirrels may seriously damage plantings. You may be able to avoid damage by planting well away from burrows. Acorns and young seedlings may be protected by caging above and below ground. Removing attached acorns from transplants may make them less attractive to ground squirrels. Alternatively, ground squirrel populations may be reduced with approved control methods such as trapping and baiting. (Go to E5)
	NO	EH. Plant well away from any active burrows. Special protective measures are probably not justified. (Go to E5)

E5. Are there high populations of pocket gophers in the vicinity?	YES	EI. Gophers may damage new seedlings or established saplings. Avoid planting near active burrows or reduce gopher populations with approved control methods such as trapping and baiting. Seedlings may be protected with below-ground caging. (Go to E6)
	NO	EJ. Avoid planting near active burrows. More intensive protective measures are probably not justified. (Go to E6)
E6. What other vertebrates are present in high populations?	TREE SQUIRRELS or SCRUB JAYS	EK. These animals may remove acorns from planting sites. Protect acorns with caging or flat wire mesh, or bury acorns 4-5 cm (1.5-2 in) deep and cover with a layer of mulch to reduce depredation.
	RABBITS	EL. Browsing of seedling shoots by rabbits may significantly reduce growth. Seedlings can be protected with cages. Registered repellents may also provide control.
	MICE/VOLES	EM. These rodents will sometimes damage acorns and young seedlings. Screening or small-mesh wire cages can be used to protect seedlings and acorns.

Section F. General planting recommendations

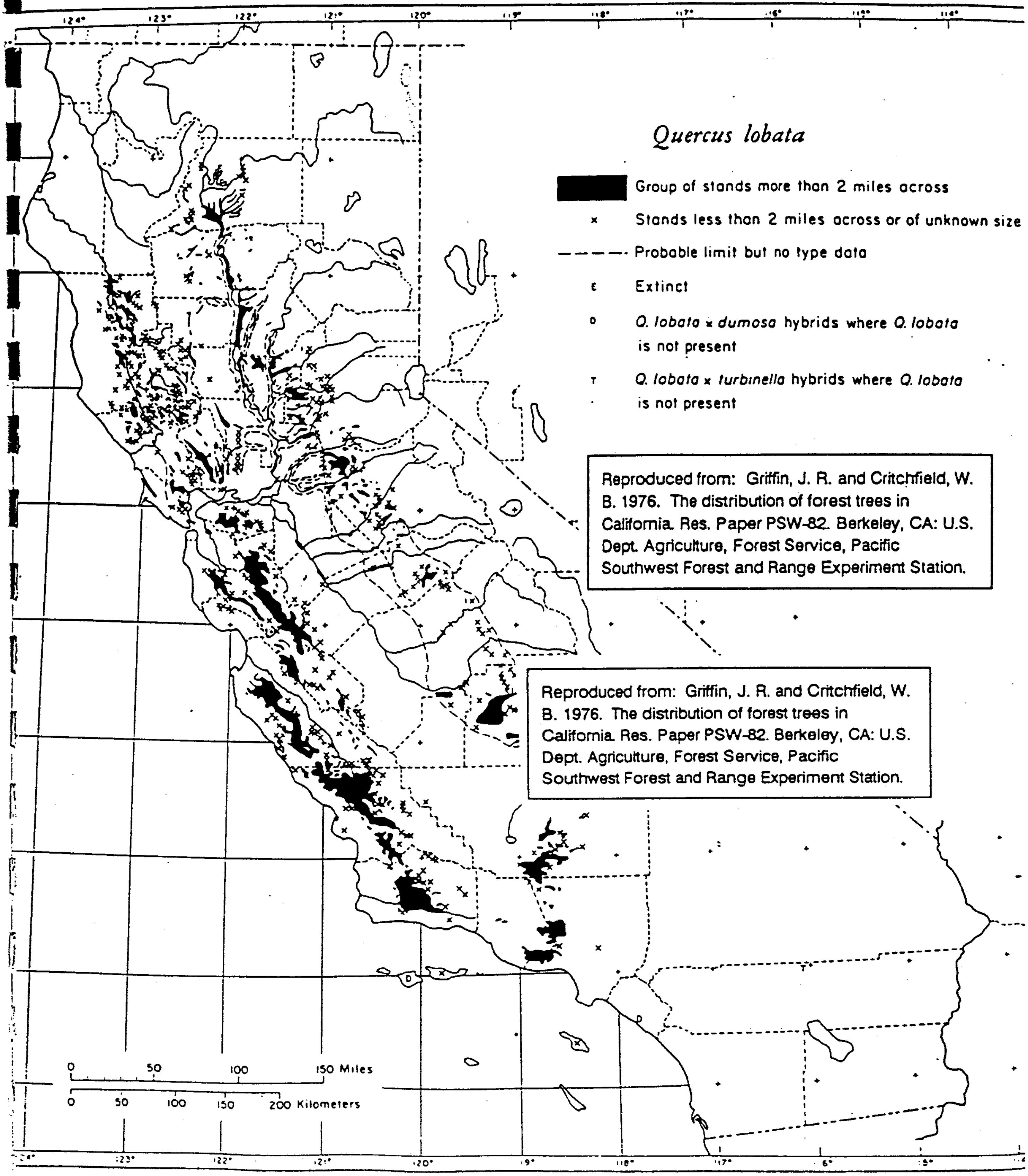
Planting may be accomplished with either acorns or transplants. However acorns have several advantages over transplants and are recommended for most projects (see page 7).

Planting date: Acorns or transplants should be planted in the fall after the first rains.

Acorn collection and storage: Collect acorns from local trees. Acorns picked from the tree in the early fall will have lower rates of damage than those collected from the ground. Discard any acorns that are very lightweight or have insect exit holes. Store acorns refrigerated in plastic bags until planted.

Planting methods: Depending on acorn quality, plant two to four acorns at each planting site to ensure that at least one will germinate. In most soils, acorns can be planted at a depth of about 4-5 cm (1.5-2 in). To compensate for attrition, plant at a density of approximately two to three times the final desired tree density.

Site modifications: Use a synthetic or organic mulch over the planting site to conserve soil moisture and promote seedling survival and growth. If protective exclosures are required, install them at the time of planting. If tillage or augering is required, do not work soil while it is wet.



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Minimum input techniques for valley oak restocking[1]

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Abstract: We set up experiments at four locations in northern California to demonstrate minimum input techniques for restocking valley oak, *Quercus lobata*. Overall emergence of acorns planted in 1989 ranged from 47 to 61 percent. Use of supplemental irrigation had a significant positive effect on seedling growth at 2 of 3 sites. Mulch, of organic materials or polypropylene landscape fabric, significantly increased growth at all 4 locations. Seedlings enclosed in individual wire cages were effectively protected from browsing by deer or cattle.

The valley oak, *Quercus lobata* Neé, has been eliminated from much of its former range in California due to clearing for agricultural and urban development. Furthermore, natural regeneration may be insufficient in many parts of its remaining range to maintain current stand densities (Bolsinger 1988, Muick and Bartolome 1987). Artificial regeneration is therefore necessary to restore many stands that have been lost or degraded. Effective, low-cost restocking techniques are needed if significant areas of valley oak woodlands are to be restored.

To gain insight into the influence of restocking techniques on survival of valley oak in restocking projects, we visited and evaluated a number of valley oak restoration projects throughout California that were undertaken in the past 10 years. Overall, water deficit and vertebrate damage were the most important factors affecting seedling survival at the sites we evaluated (Swiecki and Bernhardt 1989). These factors are also the most commonly cited constraints to seedling establishment reported in the literature (Danielsen 1990, Griffin 1971, Gordon and others 1989, Knudsen 1987, Rossi 1980). We incorporated information from our review of these past restoration projects and from the literature into a conceptual model that indicates the types of inputs required to obtain successful seedling establishment under different site conditions (Swiecki and Bernhardt 1989).

In 1989, we established a number of demonstration projects designed to test the assumptions of our conceptual restoration model. The projects are located at four sites in northern California. Valley oaks are present in the vicinity of all project sites, but had been reduced to relict stands or completely eliminated within the areas selected for restocking. Restocking methods selected for each project were tailored to the site conditions and represented varying levels of cultural inputs, starting from the minimum deemed necessary to establish seedlings. This paper reports the results of restocking techniques for the first season at all sites and the second season in one location.

METHODS

We set up demonstration projects at four sites: the California Academy of Science's Pepperwood Ranch Natural Preserve in Sonoma County; the Napa County Land Trust's Wantrup Wildlife Sanctuary in Napa County; The Nature Conservancy's Cosumnes River Preserve in Sacramento County; and the City of Vacaville's Hidden Valley Open Space reserve in Solano County.

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General methods

At all locations, locally-collected acorns were used and volunteers assisted with the plantings. The Cosumnes site was planted in December of 1988. All other locations were planted from late October through early November of 1989 as described below. For most treatments, planting sites were prepared by turning over and breaking up the soil with a shovel. At each site, 4 intact acorns were planted on their sides at a depth of about 5 cm, spaced 15 cm apart in a square pattern. At Wantrup, soil was not turned over prior to planting, and acorns were inserted into cracks in the soil opened up with a shovel.

At all locations except Cosumnes, individual seedlings were protected from browsing by deer or cattle with one of two types of protective cages, both of which were 122 cm tall and about 45 cm in diameter. The cages were made of readily available materials and designed to minimize costs of materials and installation. Individual exclosures to protect seedlings from browsing by both cattle and deer (Vaca cages) were constructed of welded 2 x 4 in mesh galvanized 12 gauge wire fencing. Each cage was secured on one side to a T-post and on the opposite side by a 86 cm length of steel reinforcing bar (rebar) which was driven into the soil at least 30 cm. Cages to prevent deer browsing (deer cages) were not designed to withstand cattle and were only used in nongrazed areas. They were constructed of lightweight 1 in diameter wire mesh (poultry netting). Deer cages were secured to a 150 cm length of rebar or a T-post on one side and a 60 cm length of rebar on the opposite side. Relative costs of the materials and approximate times required for exclosure construction are shown in Table 1.

Table 1. Cost (1989) and labor estimates for components of some treatments.

Treatment	Materials cost	Assembly time	Installation time/site
Vaca cage	$5.36	5-6 min	5-7 min
Deer cage	$2.92	4-5 min	3-4 min
Landscape fabric	$1.04	1-2 min	1-2 min
Drip irrigation[1]	$174.30	-	-

[1] 1000 ft drip line, emitters, and fittings for 50 sites

Nonwoven polypropylene landscape fabric (Typar^R, Reemay, Inc.) was used to mulch sites in some treatments. The material was cut in 90 cm squares, and 2 slits about 30 cm long were cut in a 'X' pattern in the center of each square. The fabric was fastened to the ground with a 10 cm long steel staple in each corner after the acorns were planted. The Typar^R fabric, which breaks down when exposed to UV, was covered with 5-7 cm of wood chip mulch following the manufacturer's recommendation.

Data on seedling emergence, condition symptoms, and height were recorded periodically for each location. Unless otherwise noted, height and survival data presented here were collected between 15 August and 27 August 1990, and emergence data is cumulative to this period. Both mean seedling heights and height of the tallest seedling for each planting site were calculated and analyzed. In all cases, results for both were similar, and only the heights of the tallest seedling are reported.

We analyzed the effects of treatments on emergence and condition frequencies using contingency tables and categorical data modeling procedures. Heights were analyzed using analysis of variance. Mean separation in preplanned comparisons was made using least significant difference following a significant F ratio. Where experimental designs became unbalanced due to missing data, least square means (SAS Institute, Inc. 1988) were used. Single degree-of-freedom contrasts were also used to test for differences between selected treatments. The significance level of differences and effects referred to as significant is $P \leq 0.05$.

Vacaville

The Vacaville location was chosen as the more favorable of 2 available planting locations on city-owned land. It is an urban open space buffer between housing developments, and consists of two adjacent south-facing hillsides of about 7 acres each. A remnant oak woodland which includes valley oak and interior live oak *(Q. wislizenii* A. DC.) is present on the top of the easternmost hillside. Herbaceous vegetation is largely annual grasses and forbs, but substantial populations of purple needlegrass *(Stipa pulchra* Hitchc.) are spread across both hillsides. Short duration grazing was used in the spring of 1990 for fire suppression. The east hillside was grazed from 28 March to about 23 April at a density of one head per acre. Cattle from an adjoining field were allowed access to the western hillside from 1 April to about 15 May. Soil is a clay loam averaging 75-100 cm deep. We detected subsurface compaction in various spots across both hillsides and exposed rock is visible near the crest of both hills.

At the start of the project we anticipated that damage by cattle, moisture stress due to weed competition, soil depth and compaction, and vandalism would be the most likely factors to limit restocking success. Vaca cages were installed on all but a single treatment to protect seedlings from cattle. Landscape fabric mulch was used on two treatments to reduce weed competition and conserve soil moisture. A thin mulch of dry grass was used in the remaining treatments. Two different methods were used to compensate for soil compaction. In one treatment, a two-person power soil auger with a 10 cm diameter bit was used to loosen the soil to a depth of 45 to 60 cm. For two other treatments, we probed the soil at potential planting sites with a 6 mm diameter steel rod in an attempt to differentiate between more and less favorable microsites. Sites where the probe could be inserted to a depth of 45 to 60 cm were assigned to the "deep probe" treatment, and sites where the probe could be inserted no more than 30 cm were assigned to the "shallow probe" treatment.

Overall, 5 treatments were tested in this location, with 30 planting sites per treatment on each hillside. The treatments were:

V1. No protection, grass mulch, sites prepared only with a hand trowel at planting.
V2. Vaca cage, grass mulch, deep probe sites.
V3. Vaca cage, grass mulch, shallow probe sites.
V4. Vaca cage, landscape fabric mulch, nonaugered sites.
V3. Vaca cage, landscape fabric mulch, augered sites.

Pepperwood

The Pepperwood Ranch Natural Preserve is located in the North Coast Ranges between Santa Rosa and Calistoga. The planting locations are two adjacent fields, one currently grazed by cattle and the other nongrazed. A few mature valley oaks are present around the edges of the nongrazed field. Cattle had access to the grazed field from late October to mid May, and there was little residual herbaceous cover at the end of this period. The nongrazed field has a heavy weed cover, with high populations of Harding grass (*Phalaris tuberosa* L. var. *stenoptera* [Hack.] Hitchc.), although other weeds and native grasses including *Stipa pulchra* are also present. The topography of both meadows is very uneven and soil depth is variable, with areas where the underlying bedrock is exposed or very close to the surface. Soil texture is a clay loam. Wet seeps and seasonal creekbeds are present in parts of the fields.

We anticipated that browsing by cattle and deer and water stress due to shallow soils and weed competition would be the major factors limiting restocking. To avoid the limitation of soil depth and make the best use of available soil moisture, we concentrated our planting sites along the seeps and creekbanks, and avoided areas with extremely shallow soil. We tested both landscape fabric and wood chip mulches for weed control and moisture conservation. An irrigated treatment was also tested in the nongrazed field. Sites were irrigated once a month, beginning 1 June and ending 1 Sept. Each plant received approximately 40 L of water per irrigation through 4 L/h drip emitters. All sites in the nongrazed field were protected with deer cages and those in the grazed field were protected with Vaca cages.

We planted 40 sites per treatment in the grazed field, and 24 to 33 sites per treatment in the nongrazed field. The treatments were:
P1. No mulch (both fields).
P2. Wood chip mulch (both fields).
P3. Landscape fabric mulch (both fields).
P4. Landscape fabric mulch, irrigated (nongrazed field only).

Wantrup

The Wantrup Wildlife Sanctuary planting sites are located on the nearly level floor of the Pope Valley. Large valley oaks are widely scattered across the valley floor and a higher density of mature oaks is found along a seasonal creek channel that crosses through the planting site. Soil averages 30 cm of silty loam overlying silty clay loam to a depth of 150 cm or more. We planted in 3 adjacent fields. Field 1 has been grazed heavily for many years, and is currently grazed from December through June. There is little residual herbaceous cover after seasonal grazing. Field 2 is an area surrounding the seasonal creek, which was fenced to exclude cattle about 5 years earlier. Weed cover is very dense and includes heavy stands of Harding grass and yellow star thistle (*Centaurea solstitialis* L.). Field 3 had been grazed less heavily than field 1 in previous years, and was not grazed at all in 1990. The weed cover is intermediate between fields 1 and 2, and is dominated by Harding grass.

Browsing by deer and/or cattle, moisture stress due to weed competition, and damage by rodents were the factors which we anticipated would limit restocking at this location. Vaca cages were used in the grazed field and deer cages in the remaining fields to protect seedlings from browsing. Most planting sites were chosen to avoid areas of high rodent activity, although some planting sites in field 1 were intentionally located in close proximity to an active ground squirrel colony for comparative purposes. Several methods of weed control were also tested. In each field, a strip about 4 m wide was tilled in September 1989 with a tractor-mounted disc to remove weeds. Sites were planted in the tilled areas and in adjacent nontilled areas in each field. Planting sites were alternately mulched with moldy hay at planting or left nonmulched. For one treatment in the nontilled portion of field 2, applications of glyphosate (Roundup[R]) were made 1 month prior to planting and again in the winter 1 to 2 months after planting for weed control. The herbicide was applied in a 150 cm radius around the planting site, avoiding the area immediately adjacent to planting site in the postplanting application. A drip irrigation treatment was also tested in the untilled portion of field 3. Plants were irrigated once weekly with 20 L of water per site, starting 13 May 1990.

The basic planting was set up as a 3x2x2 factorial: 3 fields with nontilled/tilled and nonmulched/mulched treatments in each. Twenty sites were planted for each treatment. The 3 treatments tested in addition to the 12 treatment combinations from the factorial design were:
W13. Field 2, nontilled, nonmulched, herbicide.
W14. Field 3, nontilled, nonmulched, irrigated.
W15. Field 3, nontilled, mulched, irrigated.

Heavily-browsed natural valley oak seedlings and saplings were located in some parts of field 1. On 6 June 1989, we set up several types of protective cages around 26 of these seedlings and saplings. An additional 27 unprotected valley oak seedlings and saplings were paired with nearby protected plants of similar height and condition. Four protected and 6 unprotected saplings were located within an area bounded by a 120 cm tall barbed wire fence that excluded cattle but not deer. Heights of all seedlings and saplings were measured at the start of the experiment and remeasured on 21 August 1990.

Cosumnes

The Cosumnes River Preserve is on level ground in the Sacramento Valley. We set up 2 experiments in a 4 acre field which had been cleared and leveled long before acquisition by The Nature Conservancy. The field is bordered by a slough with a narrow band of existing valley oak riparian forest and is infrequently flooded in the winter. The soil is a poorly drained sandy clay loam underlain by calcareous clay and a hardpan at varying depths throughout the field. Herbaceous vegetation varies throughout the field, but is generally dominated by a variety of introduced winter and summer annual grasses and forbs.

An ongoing program of valley oak restocking has been underway at the preserve, and our experimental sites were planted by Conservancy volunteers according to the standard procedures at the preserve. Planting sites were prepared by scraping all vegetation off the soil surface in a 0.5 m radius circle. Two acorns were planted at each site within a 12 cm diameter plastic collar that extended approximately 12 cm below ground. A cylinder of aluminum window screen extending about 30 cm above ground level and folded closed at the top was attached to the top of the plastic collar (Bush and Thompson 1989), and served as the only protection against vertebrates. The screen cages were opened on top when seedlings shoots reached the tops of the cages. Planting sites are arranged on a regular grid and spaced about 3 to 4 m apart.

Since plantings were already in place at the start of our project, we limited our treatments to modifications of the Preserve's currently used post-planting inputs. Sites are routinely irrigated biweekly from the beginning of June through the end of August via drip irrigation with approximately 32 L applied per irrigation. Our experimental treatments included the reduction of irrigation frequency from biweekly to monthly, foregoing irrigation entirely, and using a mulch around the planting site for weed control and moisture conservation.

In plot 1, on the southern end of the field, a 2 x 2 factorial design was employed to test effects of irrigation frequency (2 or 4 week) and mulching, with 53 to 55 sites per treatment. Hay mulch was applied to mulched treatments on 31 May 1989. On the northern portion of the field (plot 2), alternate rows received the standard biweekly irrigation (67 sites) or were not irrigated (79 sites). All irrigated treatments received their first irrigation on 2 June 1989. Planting sites where seedlings were already dead or had not emerged by 31 May 1989, were excluded from the experiments. Some sites were lost in 1990 when a fire break was plowed along one side of the planting. Height data was recorded every 2 weeks throughout the irrigation season in 1989 and 1990, and heights at the end of the first season were recorded 21 November 1989.

RESULTS

Seedling emergence

At Vacaville, overall, 61% of planted acorns produced seedlings. The percent of sites with at least one emerged seedling did not differ significantly between treatments or fields, and ranged between treatments from 89 to 100 percent. When monitoring the planting in the spring of 1990, we found that the landscape fabric was misaligned at many of the sites. To ensure seedling emergence, we enlarged the slits in the fabric or repositioned shoots that were trapped under the fabric. Had this not been done, overall emergence in the fabric mulched sites would have been decreased.

At Pepperwood, 47% of the planted acorns produced seedlings. Emergence by planting site was significantly higher overall in the grazed field (89 percent) than in the nongrazed field (74 percent). Emergence by site was greatest overall in the wood chip mulch treatment (96 percent) and lowest overall in the nonmulched treatment (73 percent). While rates of emergence for these treatments was similar in both fields, emergence through the landscape fabric mulch was much lower in the nongrazed meadow (58 percent of sites) than in the grazed meadow (95 percent of sites).

At Wantrup, 53% of the planted acorns produced seedlings. There were no significant differences in emergence between the 3 fields. A significantly higher percentage of nonmulched sites (87 percent) had emerged seedlings than did mulched sites (77 percent). Emergence was also higher in sites that had been tilled (92 percent) than in the nontilled sites (71 percent).

Seedling growth

At Vacaville, average heights of the tallest seedling at each site differed significantly between treatments and hillsides in the 2-way analysis of variance. Even though cattle were on the fields at Vacaville for only 4 to 6 weeks, the average height of unprotected seedlings was significantly less than that of protected seedlings (below). There was no significant difference in height between seedlings in deep probe and shallow probe sites, or between those in augered and nonaugered sites. Among seedlings protected from cattle browsing, those mulched with fabric were significantly taller than nonmulched seedlings. Average seedling heights for all treatments were as follows:

	Average seedling height (cm)	
Treatment	East hill	West hill
V1. No protection	12	8
V2. Vaca cage, deep probe	17	16
V3. Vaca cage, shallow probe	18	14
V4. Vaca cage, fabric mulch, nonaugered	24	20
V5. Vaca cage, fabric mulch, augered	21	23

The irrigated treatment (P4) was not included in the 2-way analysis of variance for Pepperwood, since it was not replicated in both fields. In the 2-way analysis, average seedling heights were significantly greater in the grazed field than in the nongrazed field, and nonmulched seedlings were significantly shorter than those in either of the mulched treatments:

Treatment	Average seedling height (cm). Nongrazed	Grazed
P1. No mulch	8	9
P2. Chip mulch	10	13
P3. Landscape fabric	10	12
P4. Irrigated	11	-

In the 1-way analysis of variance for treatments in the nongrazed meadow, which included the irrigated treatment, there was no significant treatment effect on seedling height.

At Wantrup, average heights of the tallest seedling ranged from 8 cm in the nonmulched, nontilled treatment in field 1, to 16.5 cm in the irrigated, mulched treatment in field 3. Seedling heights in the irrigated treatments did not differ significantly from those in nonirrigated mulched treatments in the 1-way analysis of variance of all treatments. Seedling heights in the herbicide treatment were near the overall average for all treatments.

We conducted a 2-way analysis of variance of the data from field 3, with mulching and 'method' (nontilled/nonirrigated, tilled/nonirrigated, and nontilled/irrigated) as the main effects. Both mulching and 'method' were significant in the analysis of variance, but the interaction term was not. Mulched seedlings were significantly taller than nonmulched seedlings, and irrigated seedlings were significantly taller than those in the other two 'methods'.

Irrigated and herbicide treatments were omitted from the 3-way analysis of variance comparing the effects of fields, tillage, and mulching. In the full interaction model, only fields and mulching significantly affected seedling height. Overall least square means of mulched seedling heights were 12 cm compared to 10 cm for nonmulched seedlings. Seedlings growing in field 3 were significantly taller (12 cm) than those in field 1 (10 cm).

Established natural seedlings and saplings at Wantrup that were protected from grazing grew significantly more than those left unprotected:

	Average height change (cm) from 6 June 89 to 21 Aug 90 Protected seedlings	Unprotected seedlings
Area grazed by cattle and deer	+24	-5
Area grazed by deer only	+27	+2

Although deer were highly effective at suppressing height growth, saplings browsed only by deer did not exhibit net height decreases, as was common in the saplings exposed to cattle.

By August of the first growing season (1989), seedlings in mulched sites were significantly taller than those in nonmulched sites at Cosumnes Plot 1, but the effect of irrigation frequency was nonsignificant (Table 4). Due to the amount of deer browsing that occurred in the plot in 1990, we analyzed the maximum seedling height recorded during the season rather than the final heights recorded in August 1990. In this analysis, effects of both irrigation frequency and mulch on total height were significant (Table 4). We analyzed second season growth with analysis of covariance, using height in November 1989 as the covariate to correct for the influence of initial height on second-season growth. In this analysis, the differences between maximum height in 1990 and height in November 1989 did not vary significantly with treatment, although the effect of initial height was highly significant.

In plot 2, there was no effect of irrigation on height the first summer but a significant increase in height with irrigation the second summer. The large increase in height with irrigation evident the second year (Table 4) was at least partially due to increased shoot survival in the irrigated seedlings. Since many of the nonirrigated seedlings were resprouts, their shoots were shorter than those in the irrigated treatment which were able to make continued growth from the previous year's stems. The average soil depth to hardpan was shallower in plot 2 than in plot 1, and irrigated seedlings in plot 2 were considerably shorter than seedlings in plot 1 which received the same amount of irrigation (Table 4).

Table 4. Average height (cm) and percent of valley oak seedlings browsed at Cosumnes Franklin Plots 1 and 2.

Treatment	Height 22 Aug 89	Max Height 21 Aug 90	Pct browsed
Plot 1:			
Mulched, 2 week irrig	36	62	71
No mulch, 2 week irrig	27	49	53
Mulched, 4 week irrig	33	55	63
No mulch, 4 week irrig	24	39	37
Plot 2:			
No mulch, 2 week irrig	16	31	22
No mulch, no irrig	14	19	3

Seedling condition

Vaca cages and deer cages installed at Vacaville, Pepperwood, and Wantrup effectively prevented browsing of seedlings by large herbivores. Deer cages in the nongrazed areas were unmolested, but some of the Vaca cages were damaged by cattle. The most common damage was denting of the wire cylinder, which did not usually impair the cage's function. At Wantrup, light weight vineyard posts were used in place of T-posts, and 11 percent were bent by cattle. In other locations, T-posts were sometimes tilted when pushed by cattle when the soil was wet (7.6 percent at Pepperwood, 0.8 percent at Vacaville). Fourtenn gauge wire mesh Vaca cages used at Wantrup were also more seriously bent than the 12 gauge cages used at Vacaville and Pepperwood. Rarely, cattle were able to completely dislodge the protective cage. Two cages (0.8 percent) were removed by vandals at Vacaville, but were located and replaced.

At Vacaville, overall 79 percent of the seedlings which emerged were still green on 27 August 1990. Browsing damage to seedlings was visible in 26 percent of the uncaged (V1) sites and in 1 percent of the protected sites. Only 3 percent of the sites showed evidence of rodent digging and seedlings in 5 percent of the sites showed foliar damage from chewing insects.

At Pepperwood, 97 percent of the seedlings were still green on 24 August 1990. Seedlings in 13 percent of the sites showed evidence of having been browsed, presumably by gophers, mice, or voles. There was significantly more browsing in the nongrazed meadow than in the grazed meadow, and browsing was most common in the chip mulch treatment (P2). Only 4 percent of the sites showed evidence of rodent digging and 4 percent of the sites showed foliar damage from chewing insects.

At Wantrup, the percentage of green seedlings in all treatments dropped from 87 percent on 1 July to 50 percent on 1 August, and to 22 percent by 21 August 1990. This decrease was not due solely to lack of moisture, because shoot survival in the irrigated treatment dropped from 72 percent on August 1 to 27 percent by August 21. Stem girdling caused by either small rodents or insects was apparently the cause of at least some of the observed shoot mortality. Within field 3, seedlings at 96 percent of the irrigated sites were girdled, whereas seedlings at 54 percent of the nontilled sites and 32 percent of the tilled sites showed similar damage. This symptom was not observed in field 1. Overall, 6 percent of the sites showed foliar insect chewing damage.

Although seedlings in only 0.8 percent of the sites were browsed, 14 percent of sites were disturbed by rodent digging. Eighty-three percent of all disturbed sites occurred in field 1 near the active ground squirrel colony. In this field, rodent digging was significantly more common in the nonmulched sites (58 percent) than in the mulched sites (30 percent). In field 1, 76 percent of undisturbed sites but only 31 percent of the disturbed sites contained seedlings with live shoots by 21 August.

At Cosumnes plot 1, seedlings in only 3 sites (1.4 percent) had died by 21 August 1990. In plot 2, 4 percent of the plants in the irrigated treatment, but 43 percent of the plants in the nonirrigated treatment, died during the first summer and did not resprout in 1990. Thirty-seven percent of those seedlings in the nonirrigated treatment whose shoots died the first season resprouted from the crown in 1990. In plot 2 in 1990, 39 percent of the nonirrigated seedlings, but only 2 percent the irrigated seedlings were resprouts. The seedlings at Cosumnes were not protected from deer once they grew beyond the screen cages. The frequency of browsing damage during the summer of 1990 increased with increasing seedling height (Table 4).

DISCUSSION

Choosing methods for planting valley oaks in rangeland situations involves trading off the costs of cultural inputs with desired and expected survival and growth rates. The increase in growth and survival that may be obtained with high levels of cultural inputs must be balanced against the additional cost and effort expended. Furthermore, cultural inputs may have unexpected negative consequences as well as positive effects, and the balance between positive and negative effects may vary from site to site. Finally, if the limiting factors at the planting site are not adequately characterized, cultural inputs may overcome one set of limiting factors only to have growth and survival limited by other factors.

Although caging individual planting sites is relatively expensive in terms of materials and labor, our data and previous reports (Griffin 1971, Rossi 1980) indicate that protection from browsing is necessary where restocking is to occur in areas grazed heavily by either cattle or deer. Where existing seedlings or saplings can be located, such as at Wantrup, caging to protect against deer and cattle may be the only input required for restocking. Furthermore, overall costs can be reduced if cages are removed and reused after trees have grown above the browse line.

In our experience, protecting seedlings with either Vaca or deer cages has not been associated with any obvious negative effects. However, Vaca cages may require maintenance, since they can be damaged by cattle. It may be possible to reduce or eliminate maintenance requirements by using higher grade materials. For example, substituting a second T-post for the rebar stake would substantially increase the strength of the cage, but would require a higher initial investment in materials and labor. Damage to Vaca cages was lowest at Vacaville, where the period of grazing was relatively short, indicating that damage may increase with the intensity or duration of grazing. Thus, the grazing pattern should also be considered when weighing the costs and benefits of different cage designs and materials.

The necessity of protecting against damage by rodents to obtain adequate restocking is less certain. The impact of rodent herbivory on seedling establishment and growth are highly variable from location to location. For example, while Griffin (1980) reported extensive seedling destruction by gophers in the Carmel Valley, others (Knudsen 1987, Bush and Thompson 1989) found that seedling losses due to gophers were relatively minor. Knudsen (1987) blamed mice and voles for seedling and acorn losses of valley oak. An unprotected planting of valley oaks was completely destroyed by ground squirrels within weeks in a heavily-infested area in Cheseboro Canyon, whereas 60 to 100 percent of the protected seedlings in the same area survived the first year (Pancheco 1987).

In our sites, damage by rodents was insignificant at Vacaville and the nongrazed field at Pepperwood, despite a complete lack of protection against rodents. In contrast, rodent damage, primarily caused by ground squirrels, significantly reduced shoot survival in field 1 at Wantrup. However, since severe rodent damage was localized near an obviously active colony, reasonable control of rodent damage could be obtained at this location by simply avoiding the most heavily colonized portions of the field. The cup and screen planting method, which was used at Cosumnes, was developed in part to protect seedlings from herbivory by rodents and insects. However, due to the variable nature of rodent damage, and the low overall incidence of insect damage, this particular input is probably unnecessary in many locations. Furthermore, in favorable sites, screens must be opened within the first growing season to accommodate seedling growth. Considering the labor required for installation and follow-up maintenance, the relatively short period of protection provided, and the need for supplemental protection in areas grazed by cattle or deer, the usefulness of this technique for valley oak restocking may be limited to rather specific situations.

Competition for soil moisture may be an important factor limiting natural regeneration in many areas. Introduced Mediterranean annual grasses and forbs have largely replaced native perennial bunchgrasses in the oak understory (Gordon et al 1989). There is experimental evidence to support the widely-held belief that introduced annual grasses and taprooted forbs deplete soil moisture more rapidly than native perennial grasses (Danielsen 1990, Gordon et al 1989). Knudsen (1987) noted that survival of natural valley oak seedlings increased as grass density decreased. Griffin (1971) obtained 100% seedling establishment from valley oak acorns planted in cleared plots during a drought year (1967-68), while all seedlings died by May in adjacent grassy plots.

Methods to conserve soil moisture include mulching and weed control. Both the synthetic and organic mulches we used significantly increased seedling height at every location, and data from Cosumnes showed a clear benefit of mulching even among irrigated sites. Mulch not only conserves soil moisture but also serves to moderate soil temperatures (Brady 1974) which may have a beneficial effect on root growth. At Pepperwood, wood chip mulch was as effective as landscape fabric in promoting emergence and growth, and may be the preferred treatment because of the lower input required.

Irrigation is commonly used to augment soil moisture. However, the relatively high cost of materials (Table 1) and labor associated with this input generally limits its use in extensive restocking of rangelands. Although irrigation increased seedling growth at Cosumnes and Wantrup, it had no significant effect on seedling height in the first season at Pepperwood. Furthermore, shoot survival at Wantrup was not significantly better in the irrigated treatment than in several of the nonirrigated mulched treatments. Continued monitoring of long-term growth and survival is necessary to determine the relative effectiveness of moisture conservation versus augmentation. However, we were able to successfully establish moderate to high percentages of oak seedlings without irrigation in several locations in the third year of drought conditions.

Several cultural inputs showed unexpected negative consequences. At Wantrup, irrigated seedlings suffered more chewing damage to their stems than did nonirrigated seedlings, resulting in decreased shoot survival rates. Although mulch increased seedling growth, some mulched treatments showed lower rates of seedling emergence. At the Vacaville site, we found that the installation method we used frequently resulted in faulty alignment of the slits in the landscape fabric relative to the emerging seedlings. We expect that this problem may also have contributed to the low emergence at sites mulched with landscape fabric in the grazed meadow at Pepperwood. The hay mulch used at Wantrup may also have acted as a barrier to seedling emergence.

In some cases, cultural inputs may overcome one set of limitations only to have growth and survival limited by other factors. For example, at Cosumnes, irrigation is being used to accelerate plant growth by alleviating soil moisture limitations. As a result, browsing by deer may now be the most important factor limiting plant growth. Data collected during 1990 showed that the deer most frequently browsed taller seedlings (Table 4). We believe that the lack of significant treatment effects on growth from November 1989 to August 1990 may in large part be due to deer browsing of the most vigorous seedlings. Due to the high planting density at this site, some seedlings may be able to escape deer browsing long enough to get above the browse line. However, in areas with high deer populations and low tree densities, even frequent irrigation may not accelerate plant growth enough to offset deer browsing impacts.

The effects of the treatments presented here are known only for the first 1 to 2 seasons after planting. However, it does appear that valley oaks can be restocked using low input techniques tailored to overcome site limitations. Continued monitoring of the plantings will be necessary to determine if treatment effects persist or become damped out as seedlings become more established. Results from previous projects (Swiecki and Bernhardt 1990) indicate that long-term survival may bear little relation to first year survival. With longer-term survival data, the cost-effectiveness of the different inputs could be calculated on the basis of the cost in materials and labor per each successful seedling.

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